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# BIOLOGY

## Living Systems

Oram · Hummer · Smoot

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# BIOLOGY

## Living Systems

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Fourth Edition

**Charles E. Merrill Publishing Company**
A Bell & Howell Company
Columbus, Ohio

*Toronto, London, Sydney*

## A MERRILL SCIENCE PROGRAM

*Biology: Living Systems,* Pupil's Edition & Teacher's Annotated Edition
*Probing Levels of Life: A Laboratory Manual,* Pupil's Edition & Teacher's Annotated Edition
*Laboratory Biology: Investigating Living Systems,* Pupil's Edition & Teacher's Annotated Edition
*Biology: Living Systems, Evaluation Program* (Spirit Duplicating and Black Line Masters)

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**ISBN 0-675-07032-5**

Published by
Charles E. Merrill Publishing Company
A Bell & Howell Company
Columbus, Ohio 43216

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# PREFACE

*BIOLOGY: Living Systems,* Fourth Edition, maintains the high standards of the previous editions while adding new and current material of prime importance to high school students. Input from hundreds of teachers has played a role in updating, rewriting, and reorganizing this edition. Emphasis is placed on broad concepts applicable to all living systems. Details concerning the diversity of processes, structures, and organisms are related to the unifying principles and features of all life. Basic concepts are repeated at different points and at varying degrees of depth. Thus, the student builds upon the foundation of previously mastered ideas.

Living systems are characterized by organization. Maintenance of this organization depends on the interrelationship of matter and energy. *BIOLOGY: Living Systems,* Fourth Edition, begins by introducing these important concepts. The relationship is then emphasized and repeated throughout the text as it applies to different levels of biological organization.

Uniqueness of science is then discussed. Whenever possible, important principles and concepts are presented and developed on the basis of the experimental evidence supporting them. Thus, the student gains an insight into, and an appreciation for, the way scientific knowledge is produced. The text stresses the interrelationships and differences among facts, observations, interpretations, and experimentation. It also stresses that scientific theories are always subject to revision in the light of new evidence. Evolution, for example, is treated as a theory rather than as fact.

Chemical aspects of living systems are a basic part of today's biology. Only those principles of chemistry needed for an understanding of biochemical processes are presented. When these processes are presented with other concepts, the significance of the processes is emphasized. Chemical details are minimized. A chapter on energy ties the chemical aspects of living systems to the following chapter which explores cell structure and function.

Following the introductory unit, reproduction is analyzed in terms of the cell, genetics, and biochemistry. The text then proceeds to a discussion of the evidence regarding change in living things. Adaptations, speciation, and human origins are considered. Succeeding chapters deal with principles of taxonomy and a survey of the five kingdoms.

The next three units are devoted to the anatomy and physiology of simple organisms, plants, and animals respectively. Because these three groups of organisms are adapted to very different ways of life, it is more practical to present these organisms separately. Therefore, a major change in *BIOLOGY: Living Systems,* Fourth Edition, is the separation of anatomy and physiology of simple organisms, plants, and animals into different units. However, the organization of all three units is similar so that if preferred, systems of all may be presented concurrently.

The book concludes with a unit on environment. Chapters in this unit include an examination of behavior, population biology, and ecology. An analysis of the role of humans in causing, coping with, and solving contemporary problems of pollution, conservation, and overpopulation is incorporated.

The content is presented in a logical manner—from the simplest to the most complex level of biological organization. However, the presentation is flexible enough so that chapters may be studied in a variety of sequences.

Many aids to student learning are incorporated into the text. Each unit begins with a discussion and a photograph that provide a preview of the material to be covered. A chapter-opening photograph and an introductory paragraph are used to convey the theme of each chapter to the student. A goal statement identifies the major objectives of each chapter. Margin notes, section-end and chapter-end questions, vocabulary lists, and chapter summaries provide guides for self-assessment, review, and study. Reading lists, project ideas, appendices (including information on biology related careers), a complete glossary, and an extensive index complete the many learning aids. Together, these features provide a guide by which students may efficiently approach their study of biology.

Biology, as a study of life, is a relevant and vital discipline. *BIOLOGY: Living Systems,* Fourth Edition, presents basic biological principles by using examples which best illustrate these principles. Concepts and theories are augmented by practical, applied, and familiar examples and illustrations. Thus, the text appeals to non-science students as well as to those who will continue their study of science.

# TO THE STUDENT

What common bond do you share with the more than two million other known kinds of organisms on Earth? You and the other organisms are *living* things. What makes you and other life forms "alive"? What needs do you share? What activities do you all carry out? How are you all different? In what ways do you interact? How do you and your fellow living things affect the environment, and how does the environment affect you? How do you play a role in the lives of other living things?

You are about to begin a course in biology which will enable you to answer some of these questions. You may or may not consider yourself a young "scientist." You may or may not ever take another course in biology. However, what you learn in this course will be valuable to you always. Knowledge of biology will be useful and important to you now as you learn about what makes you and other living things "tick." It will also be important later in helping you make responsible decisions as an adult.

*BIOLOGY: Living Systems,* Fourth Edition, contains much interesting and up-to-date information. Understanding how to use your text will help make your study of biology easier. Each unit begins with a photograph and a discussion that preview the material in the unit to follow. Each chapter begins with a photograph and introductory paragraph which convey the theme of the chapter to you as a living system. A goal statement explains the objectives for your study of the chapter. Throughout the chapter, margin notes emphasize the major ideas. Use these notes as a self-check to evaluate your understanding of facts and major ideas. Major terms are highlighted in boldface type.

Review questions and/or problems have been placed throughout the chapter. These, too, provide a means for you to check your understanding. At the end of each chapter, a *Summary* provides a list of the major points and ideas presented. (Some of you will find it useful to read this both *before and after* reading the chapter.) A word list, *Language of Biology,* reminds you of the most important terms.

Also at the end of each chapter are sets of questions and problems. *Checking Your Ideas* is a set of questions stressing your understanding of major facts and terms. *Evaluating Your Ideas* contains questions and problems that are useful as a review of the chapter's concepts. *Applying Your Ideas* includes questions and problems which require you to apply what you have learned to new but related ideas. In addition, a set of project ideas is presented in *Extending Your Ideas.* Included among the five Appendices are *A Classification of Living Systems* and *Biology-Related Careers.* The glossary contains complete definitions of the major terms in the text. The complete index will be valuable to you in locating particular topics.

With these thoughts in mind, it is time to begin. Our hope is that your study will result in an increased awareness and understanding of yourself and your relationship with other living things. Also, we hope you will come to share with us the excitement such understanding can bring. Good luck.

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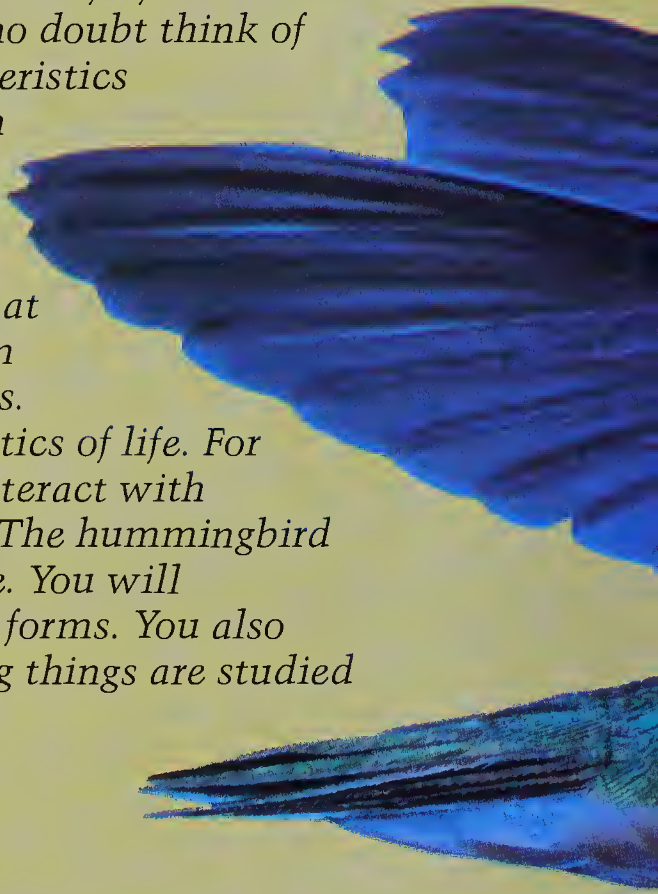
# CHARACTERISTICS OF LIFE

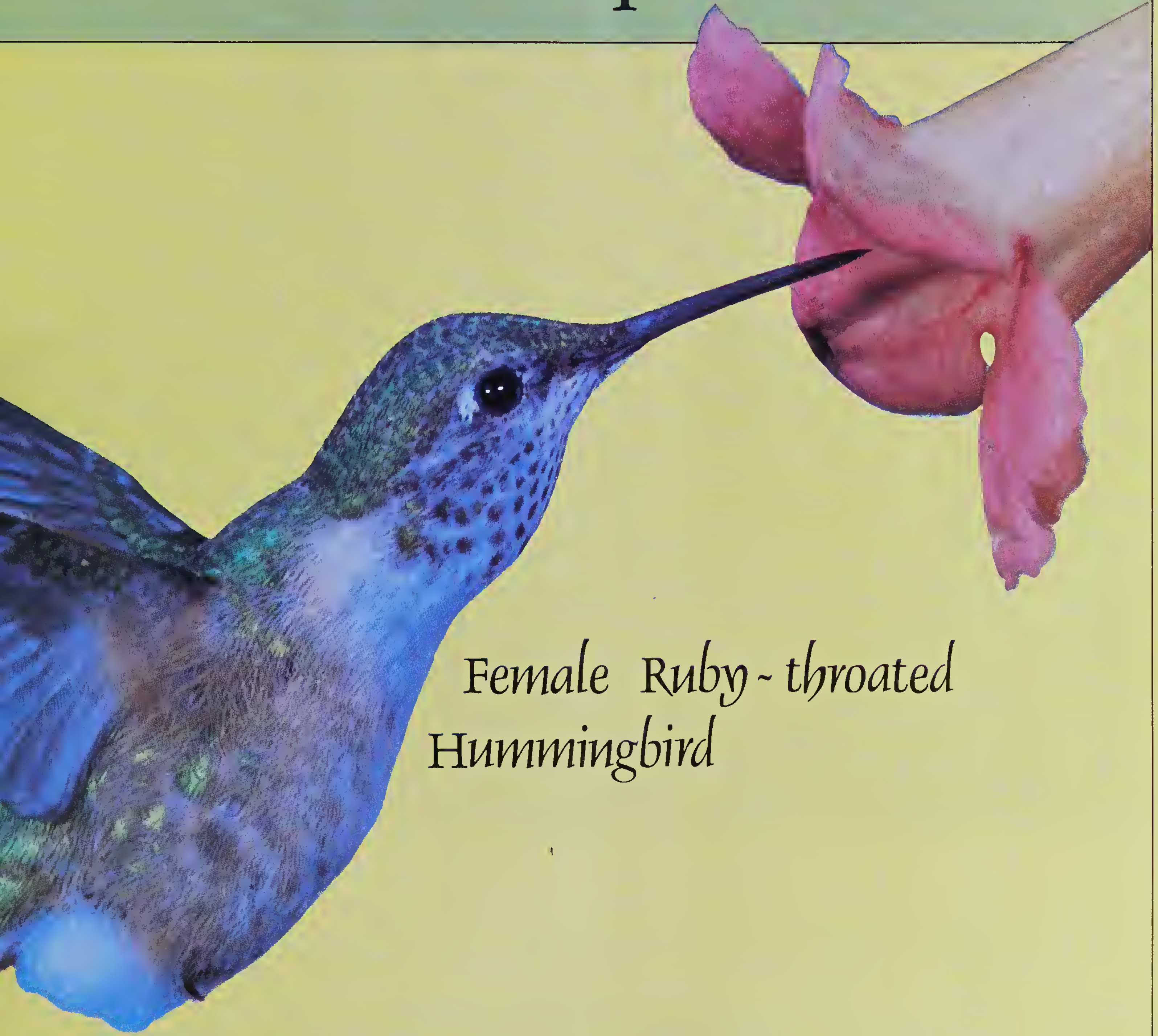
*Biology, the study of life, is a vital and challenging field. Each year that field grows as old questions are answered and new questions are raised. What determines how a living thing grows? Why do some life forms better resist disease than others? These and other questions and their answers affect you, for you are a part of the world of life.*

*When you think of living things, you no doubt think of many different kinds. Think about the characteristics of this hummingbird and the plant from which it is feeding. Think about other living things. Each life form has a special set of features; there is a great diversity in life forms. What is not so obvious is that within that diversity of life, there is unity. There are certain characteristics of life shared by all living things.*

*Unit I focuses on common characteristics of life. For example, all living things require energy. All interact with other living things and with the environment. The hummingbird interacts with plants for food, an energy source. You will learn about the characteristics common to life forms. You also will learn some of the methods by which living things are studied and you will be introduced to some ideas of chemistry needed for today's study of biology.*



# Unit
# I



Female Ruby-throated Hummingbird

Charles G. Summers, Jr. for Tom Stack and Associates

Carl W. Rettenmeyer

*If you examine the world around you, you will find it full of living things. Most easy to observe may be plants and animals, but other types of life are also present. Although the life forms seem very different, they have some things in common. All living things need food. From the food they get energy. How do living things such as these ants obtain and use energy? What is the major source of energy to the living things on Earth?*

## Chapter I

# THE WORLD OF LIVING THINGS

GOAL: You will gain an understanding of the basic features of life common to all organisms.

You are about to begin a course in **biology,** the study of life. Naturally, you want to know what you will be learning. Your study will involve different kinds of **organisms** (living things). Part of the course will examine the major groups of organisms which exist today. You will learn about the physical characteristics which set one type of organism apart from others.

Biology is the study of life.

A living thing is called an organism.

Biology is more than just a study which describes the many differences among living things. There are nearly two million known kinds of living organisms. You could not possibly learn about all or even most of them. Therefore, your study of life will focus on the similarities among organisms. These similarities most often involve the life processes of organisms—their activities and functions. By studying these processes, you will see that there are certain features common to all living things. By the time you complete the course, you will have a good understanding of what is meant by the word "life."

Organisms are similar in their activities and functions.

## THE COMMUNITY

### 1:1 Organisms

Have you ever had the chance to spend a day exploring the natural surroundings where you live? Perhaps you live in an area near a forest. Imagine that you are about to walk through the forest. As you near the edge of the forest, you see many things.

At first you see plant life such as grasses, weeds, shrubs, and other plants. As you enter the forest, you are aware of the most striking forms of life, the trees.

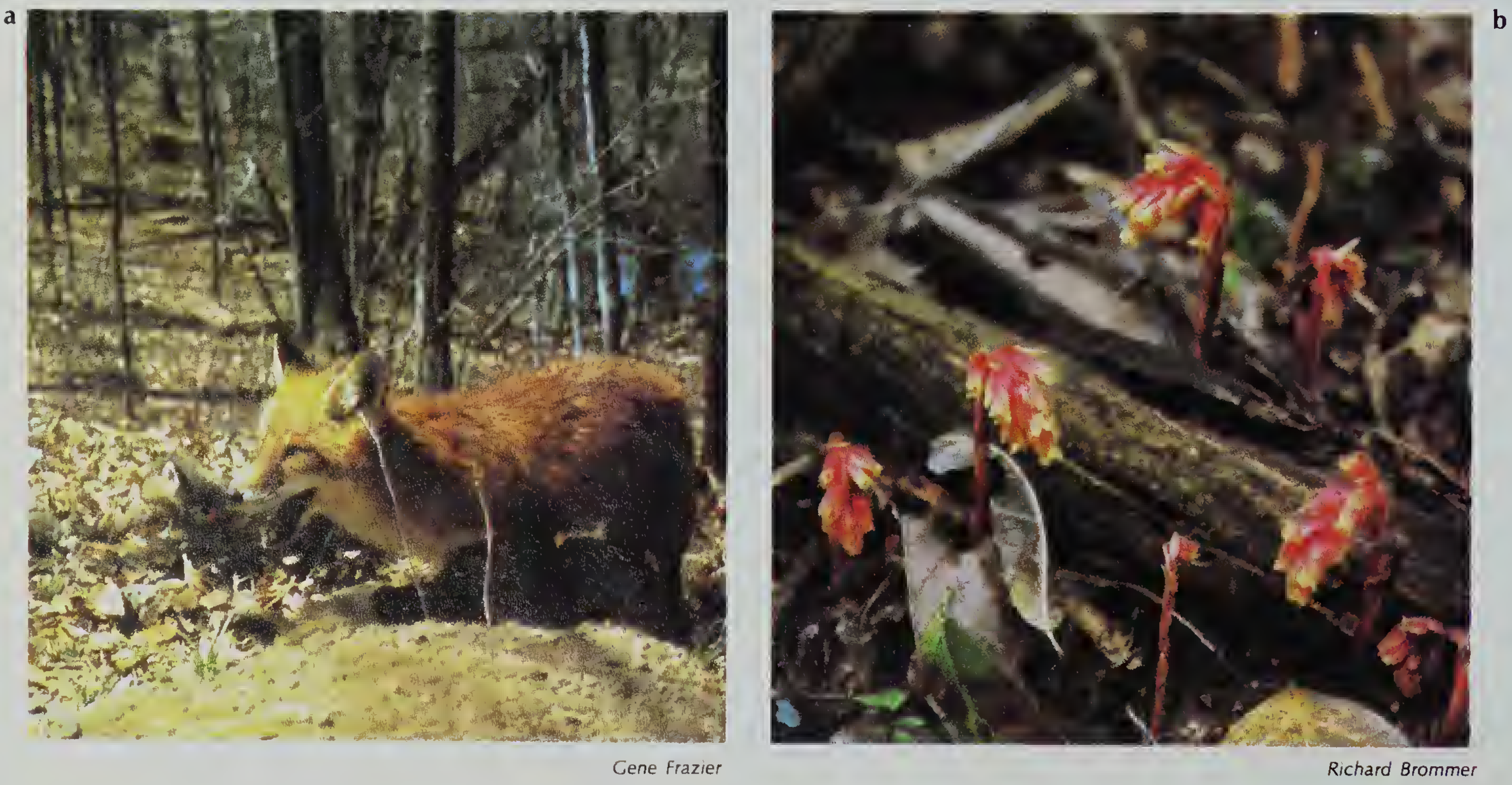
You then see much more. There are other types of plants such as ferns and mosses growing on the forest floor. Leaves and fallen branches litter the earth. You look under them and find many kinds of animal life. Insects are plentiful. Ants scurry about, each doing its special job. You see spiders, worms, and many–legged creatures. Other animal life is also plentiful. Birds sing their songs and a rabbit bounds quickly out of sight. Perhaps you see a deer nibbling leaves or a snake sliding off into the undergrowth. You look more closely at the trees and find many other living things. Bees swarm around their hive. A small butterfly, almost the same color as the bark, clings to the trunk of a tree. You also see a caterpillar moving silently across a leaf, eating as it goes.

A community is a naturally occurring group of different kinds of organisms.

Your trip has been an eventful one. Yet you saw only a fraction of the living things in such a community. A **community** is a naturally occurring group of organisms living in a certain area. You missed the countless microscopic (mi kruh SKAHP ihk) organisms that live in the soil, in puddles of water, and inside other plants and animals. If you had taken a sample of soil or water, you would have found that it contains a vast amount of life. With a microscope, you would see many bacteria, very small living things. You might also have seen many other tiny creatures, larger than bacteria and more complex. These creatures include mites and insects and very small worms.

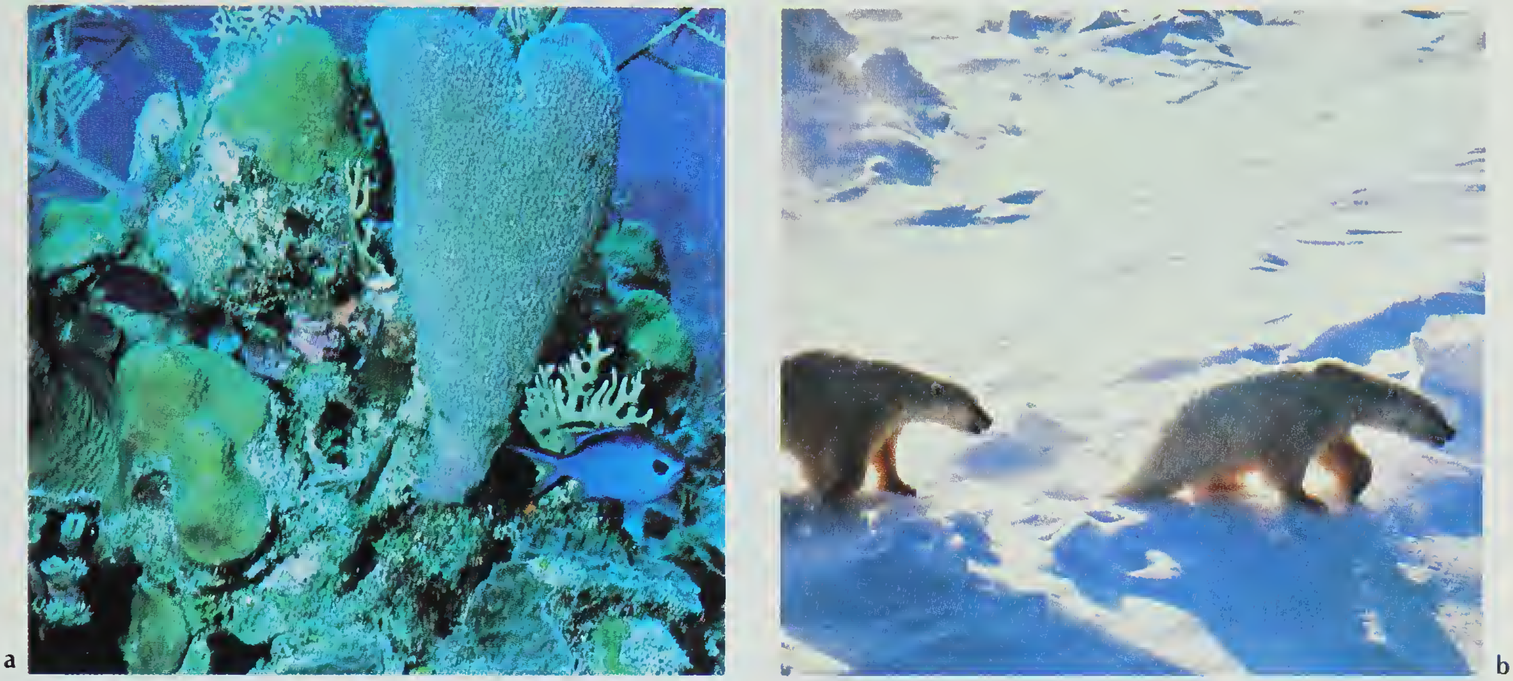
bacteria (singular, bacterium)

**FIGURE 1-1. A forest community may include organisms such as (a) red fox and (b) orange Indian pipe.**



Gene Frazier

Richard Brommer



Robert G. Bachard

Gerry Atwell/U.S. Fish and Wildlife Service

**FIGURE 1-2.** **Organisms in different communities vary. (a) An ocean reef community may include sponges, fish, and other organisms. (b) A polar community may include organisms such as polar bears.**

Maybe your surroundings are different. Perhaps you live near a grassland or desert. Perhaps you live near an aquatic (uh KWAHT ihk) community such as a pond, lake, or stream. No matter what type of community you study, each has its own kinds of living things.

From your study, one common feature of life becomes evident. Living things do not exist by themselves but exist in communities. Can you suggest some reasons? As you consider possible reasons, other common features of living things will become evident.

## 1:2 Food

Study of different communities reveals many kinds of animal life. One striking similarity among all animals is their need for food. Has it occurred to you that all animals must get their food from other living things? Some feed on other animals, some on plants, and some feed on both other animals and plants. However, in any community, there must be some organisms which can make their own food. These organisms are mainly the green plants. Most other members of the community depend directly or indirectly on green plants for food.

Animals obtain food from other organisms.

Every community includes some organisms, mainly green plants, which can make food.

Green plants are not the only living things which are able to make food. Several other forms of life, such as certain algae (AL jee) and some bacteria, can also make food. Biologists refer to all living things which make their own food as **producers.** Most producers use sunlight to produce food by a process called **photosynthesis.** Photosynthesis means "put together with light."

Producers manufacture food by the process of photosynthesis.

Gene Frazier Richard Brommer Alvin E. Staffan

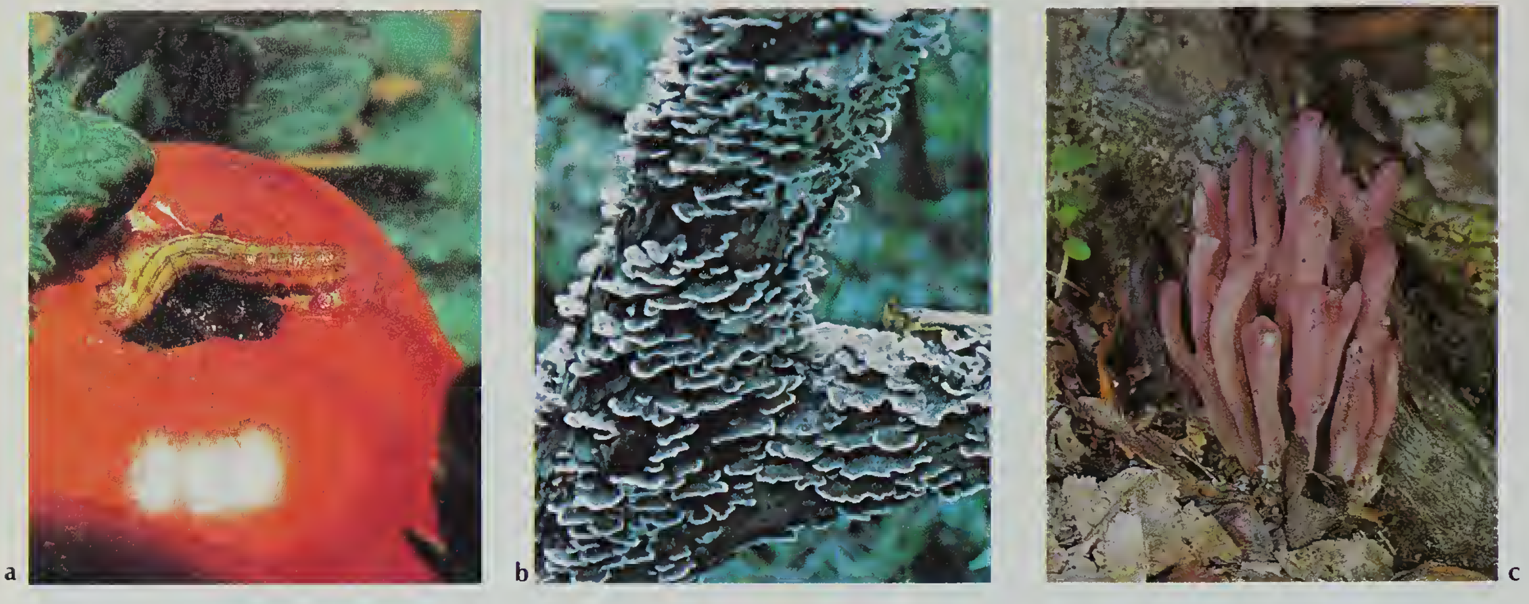


**FIGURE 1-3.** (a) A tomato slug is a consumer, eating the tomato plant, a producer. (b) A shelf fungus on a live tree is a parasite. (c) Coral fungus lives on dead matter and is a saprophyte.

The food manufactured by producers is used by the producer itself and by other members of the community. Living things unable to produce their own food are called **consumers.**

Consumers depend directly or indirectly on producers for food.

Some consumers cannot move around in search of food as most animals do. Many of them obtain food by other means. Some are **parasites,** organisms that live in or on another living thing. Parasites obtain their food from a **host** and usually harm the host. A heartworm is an animal that is a parasite inside another animal—a dog. A rust is a fungus and is an example of a plantlike parasite that grows on wheat. What are some other parasites and their hosts?

Parasites live in or on a host from which they obtain food.

Saprophytes feed on waste products of living things or upon dead organisms.

Some consumers obtain their food from dead organisms or from waste products of living organisms. These consumers are called **saprophytes** (SAP ruh fitez). A mushroom is a saprophyte which obtains its food from materials in the soil. Some bacteria and other microorganisms are saprophytes, too.

The need for food is a basic feature of living things. But there is another question to be answered. Why do all living things need food?

## 1:3 Energy

In many ways a living organism is similar to an automobile engine. Both a living thing and an engine are complex structures. Each consists of many parts which work together so the whole may function smoothly.

Energy is the ability to do work or cause motion.

In an automobile engine, all the parts have certain jobs or functions to perform. In order for them to perform, they must have fuel. Fuels are sources of energy. **Energy** is the ability to do work or cause motion. You cannot see energy, but you can see its effects. Just as gasoline is the source of energy in automobile engines, food is the source of energy in living things.

In an engine, the energy of burning gasoline sets in motion a chain of events. The result is the movement of the various parts. The energy is transferred to the wheels of the automobile. As long as fuel is available, the engine will run. As soon as the fuel is used up, the engine will stop. Similarly, each living thing must be provided with fuel if it is to function. When the fuel supply runs out, the plant or animal will stop functioning.

Automobile engines can remain inactive for long periods of time. When provided with more fuel, an engine will run again. However, living "machines" need a continuous supply of fuel. If a plant or animal is deprived of fuel for long periods of time, its parts will die. No amount of fuel supplied later will restore its ability to function.

A continuous supply of food provides energy for biological work.

Life, then, suggests a picture of constantly working machinery. There is a continuous need for fuel (in the form of food) to keep a living thing functioning. Every living thing uses the energy of food for its biological work. Obtaining and using energy is a feature of all living things.

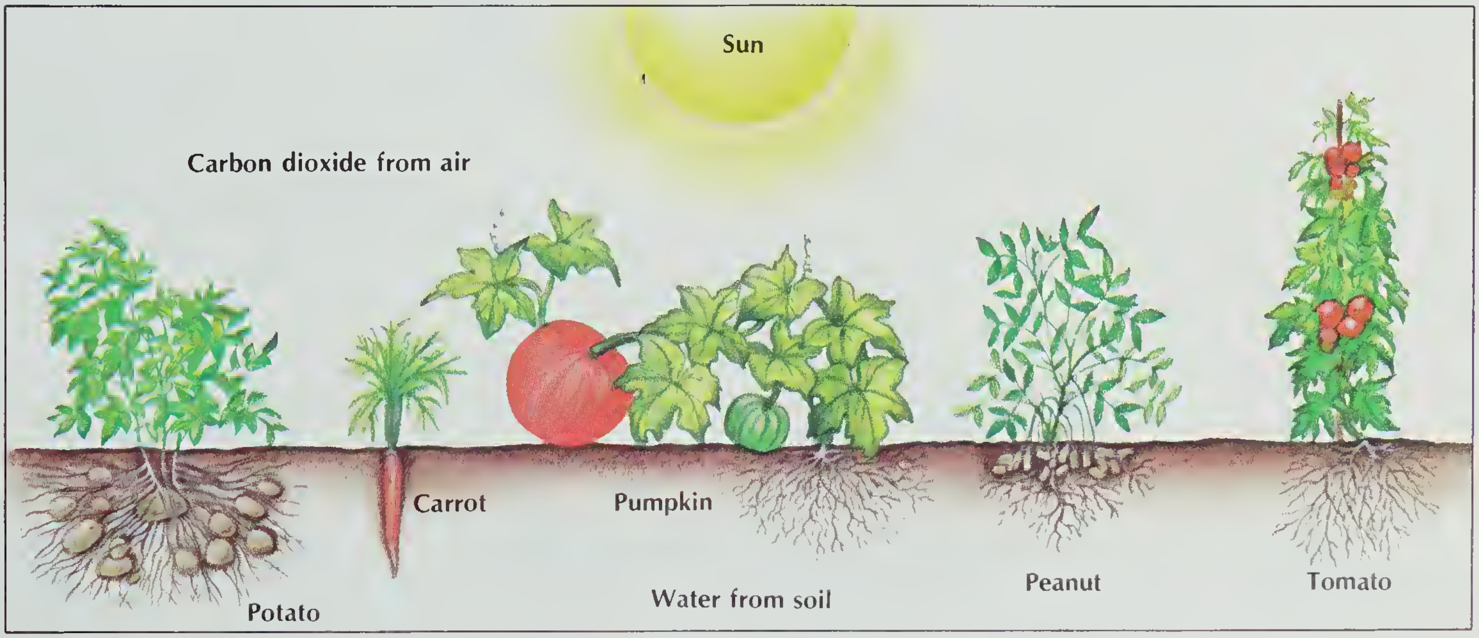
## 1:4 Food Production and Energy Transfer

Sugar is the main food used by organisms.

The type of food made by producers is sugar. It is not the same as the sugar you put on your cereal in the morning, but it is very similar. Sugar is the universal fuel for life.

Because the making of sugar involves work, energy is necessary. Most producers obtain energy for making food from sunlight. The energy of sunlight is used to combine water and a gas, carbon dioxide, to make sugar. A special substance,

**FIGURE 1-4. In photosynthesis, carbon dioxide and water are combined in green plants to make sugar. Sometimes plants convert sugars to other forms such as starches which are stored in plant parts.**



Photosynthesis requires sunlight, carbon dioxide, water, and chlorophyll.

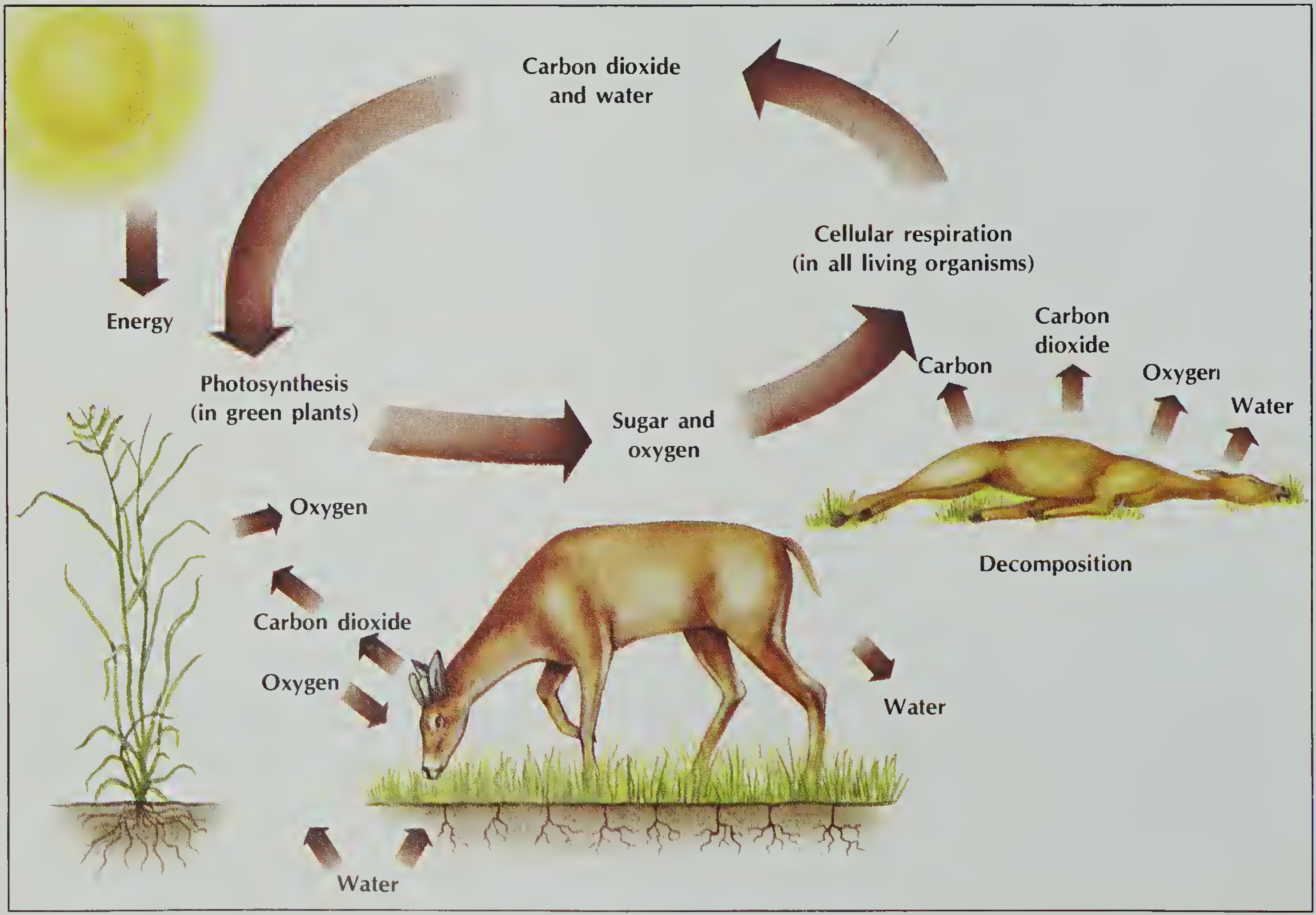
chlorophyll, is also needed. **Chlorophyll** is the substance that *traps* the energy of sunlight for use in making food. Water and carbon dioxide are obtained from the environment, but chlorophyll is made by the producer. Chlorophyll is the substance that makes plants green.

Thus, part of the sun's energy is transferred to and stored in the sugar. The sugar is later "burned" by a living thing. "Burning" of sugar is called **cellular respiration.** Cellular respiration transfers energy first produced by the sun. This energy can be used for work by a living thing.

Cellular respiration produces carbon dioxide and water, raw materials for photosynthesis.

Carbon dioxide and water are not in endless supply. How can you explain that they continue to be available to producers? During cellular respiration, sugar is broken down into carbon dioxide and water. Carbon dioxide and water are the same substances needed for photosynthesis. These substances are constantly being returned to the air. Water reaches the soil or bodies of water as rain, and carbon dioxide stays in the air or dissolves in water. These substances are used over and over again. Your body is "burning" sugar right now. The carbon in that sugar might long ago have been part of a giant fern or a dinosaur.

**FIGURE 1-5. The processes of photosynthesis and cellular respiration contribute to the recycling of materials through a community.**


Carbon dioxide and water
Energy
Cellular respiration (in all living organisms)
Carbon dioxide
Carbon
Oxygen
Water
Photosynthesis (in green plants)
Sugar and oxygen
Oxygen
Decomposition
Carbon dioxide
Oxygen
Water
Water

The "burning" process releases materials needed for photosynthesis—water and carbon dioxide. Photosynthesis, in turn, produces sugar and releases an important substance, oxygen. Oxygen is needed by most organisms to "burn" the sugar. Can you see that the "burning" process and photosynthesis are interdependent?

A producer, such as wheat, may "burn" sugar and use energy to do work. Or, a producer might be eaten by a consumer. Mice and deer, for example, are animals which feed on producers. Consumers "burn" the sugar in the producers they eat and use the energy for their own needs. A snake, in turn, may prey on (eat) the mouse, and a hawk may prey on the snake. Animals that prey on other animals are **predators** (PRED ut urz). The passage of energy from plants through a series of animals feeding on other animals and plants is a **food chain.** Wheat—mouse—snake—hawk is one food chain.

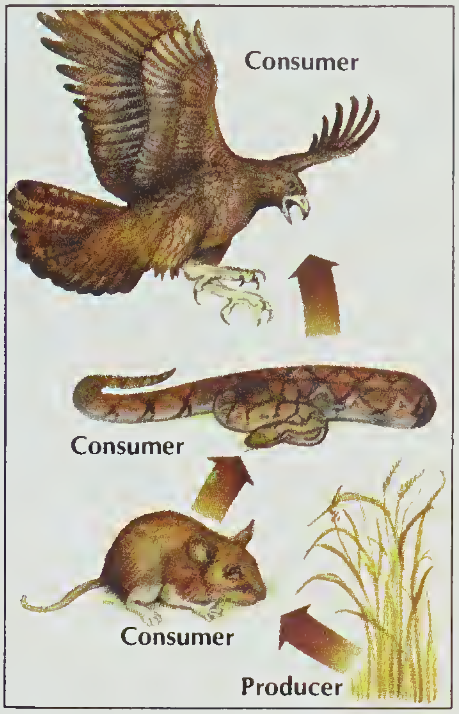


**FIGURE 1-6.** A food chain shows the direction energy moves from producer to consumers. Energy is not recycled in a food chain.

Living organisms constantly produce waste products. Eventually, the organisms die. Wastes and dead organisms are acted upon by other members in a food chain, the decomposers. **Decomposers** are organisms such as bacteria and fungi which cause decay. They are consumers. Decomposers obtain their needed energy from cellular respiration of the materials left in wastes or dead organisms. In so doing, they also release carbon dioxide and water which can be used by producers. Decomposers also return to the environment substances containing elements such as nitrogen, sulfur, and phosphorus. These elements will be used again by other living things. *Thus, in any community, the basic materials of life are recycled.*

Energy is distributed to all organisms through food chains.

Materials are recycled through a community, but energy cannot be recycled.

In a food chain, energy is passed from one living thing to another. This energy is used for each organism's work. Once the energy is used for work, though, it cannot be used again. *Thus, energy cannot be recycled.* It must always be available in the form of food. There must be a constant source of energy for photosynthesis. That energy is sunlight. Without sunlight, life as we know it could not survive.

## REVIEWING YOUR IDEAS

1. Do all living things live in communities in nature? Why?
2. What is a producer? How are producers important to a community?
3. List several examples of consumers.
4. Why do living things need food?
5. What materials are necessary for photosynthesis? What does a producer need to combine these materials to form sugar?
6. What is a food chain? Why is it important? Give an example of a food chain involving yourself.
7. Compare what happens to the materials and the energy used by a community.

# THE USES OF ENERGY

Sugar is made by producers and "burned" by all organisms. Thus, the materials and energy needed for proper functioning are made available to living things. What are these functions? They can be grouped into four broad areas: growth and development, maintenance and repair, reproduction, and organization. These functions are important because they are common features of living things.

## 1:5 Growth and Development

Every living thing has some period of growth during its lifetime. The overall growth may be slight, as of a bacterium; or it can be large, as of a whale or elephant. Whether great or small, growth is a feature of every living thing. But, what is growth, and how does it occur?

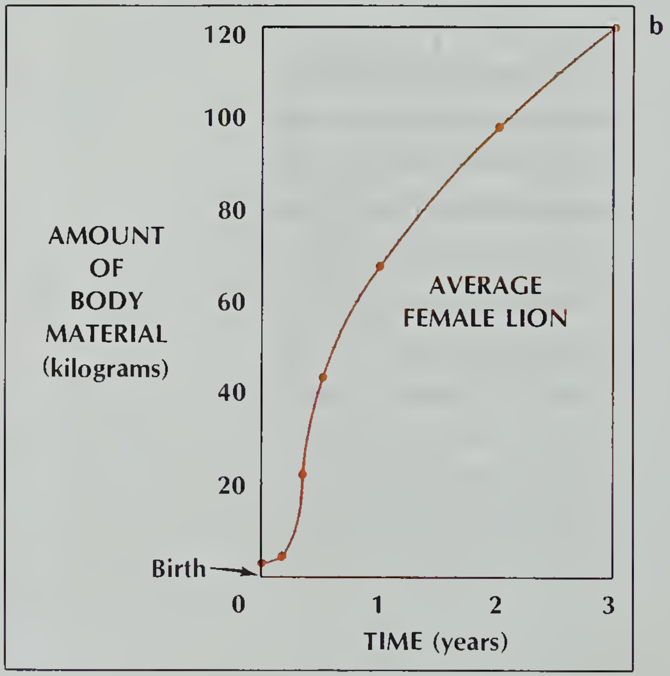
Growth is an increase in the amount of living material.

Suppose you placed a wilted lettuce leaf in a bowl of water. After a period of time, the leaf would have increased in weight and volume. Is this growth? No, **growth** is an increase in the amount of living material in a plant or animal. The lettuce leaf has not added living material; it has just absorbed water.

Consider another situation. Suppose you placed a lettuce seed in some moist soil. In about a week, a lettuce plant would begin to appear. Water was again taken in, but this time also true growth has occurred. The basic difference is that the seed has used the water (with carbon dioxide and minerals) to form living materials. Water was not just soaked up, or absorbed, in a physical

**FIGURE 1-7. Growth, an increase in the amount of living material, of (a) lions, can be shown (b) in a graph of increase over time.**

Grant Heilman



manner. It was put together with the other materials in a special way to become part of the living thing. Growth is not just an increase in amount. It is an increase in the amount of living material.

Not only did the lettuce seed grow, it became a certain kind of living thing. It became a lettuce plant with its specialized parts. How are materials put together in a lettuce seed to form a lettuce plant? Why does the seed not become a beet or carrot plant? The series of changes a living thing undergoes in reaching its final form is called **development.** The lettuce seed developed into a lettuce plant. Perhaps you know that development involves heredity (huh RED ut ee). **Heredity** is the transmission of features from one generation to the next. Later you will study both heredity and development.

## 1:6 Maintenance and Repair

Organisms respond to changes in the environment.

Homeostasis is the steady balance of the internal operation of an organism.

Organisms are faced with many changes in the environment, including the activities of other organisms. Temperatures change during a day and from season to season, and the water and food supplies can also change. A resting animal suddenly may need to flee from a predator.

If an organism is to survive such changes, somehow its internal operation must be adjusted. When you are outside in cold weather, you might shiver. A bear hibernates in the winter. A plant conserves water in dry spells. The heartbeat and breathing rates of a running animal increase. All of these features help the living things survive in their environments. How?

These responses and activities use energy. They are controlled by the interaction of many parts and systems, such as chemicals, nerves, muscles, and the skeleton. Such responses maintain **homeostasis** (hoh mee oh STAY sus), balance of the internal operation of an organism regardless of external changes. If homeostasis did not occur, organisms would not be able to live very long. Maintenance is a continual process.

What are some possible dangers to living things? A list would be endless because of the great complexity of living things. Minor problems, such as cuts and scratches or infections, usually can be overcome by natural means. Scratches heal as a result of clotting blood which covers the wound and prevents infection while new skin is being formed. Special cells in an organism often attack and destroy bacteria in an infection. Sometimes repair of an injury can even involve replacement of body parts. A salamander can replace a lost limb, growing a new limb. It also can replace other body parts. A starfish can replace a lost "arm." Much energy goes into the repair and replacement of worn-out and damaged parts in living things.

**FIGURE 1-8. Monitors on this man's chest detect his heart's response to his changed level of activity. The heart's response is part of the body's mechanism to maintain homeostasis.**

Hickson-Bender Photography

Scripps Institution of Oceanography

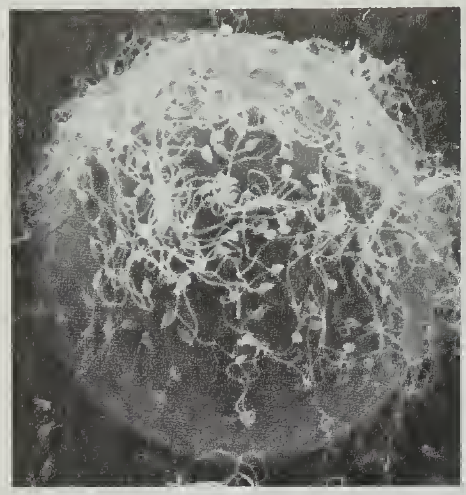


**FIGURE 1-9. Coded instructions are passed in the sperm and egg from one generation to the next. A sea urchin egg covered with sperm is shown here magnified about 800 times.**

## 1:7 Reproduction

A feature which distinguishes living things from nonliving things is **reproduction** (production of offspring). Only living things can reproduce. New plants and animals have certain features that set them apart from other kinds of living things. Rabbits produce rabbits and oak trees produce oaks. "Like produces like" is a basic biological principle. Rabbits may differ in appearance, but most people would be able to identify a rabbit.

That all living things can reproduce poses new questions. Most plants and animals begin life as a small, fertilized egg. How do you explain that from this small structure a fully grown, complex oak tree (or octopus, or orangutan) is produced?

During reproduction, a set of coded instructions is passed from one generation to the next.

A fertilized egg does not contain a small form of the living thing. What does it contain? Analysis shows that a fertilized egg is composed of many chemicals but is mostly water. Some of these chemicals direct the putting together of other materials so that a distinct living thing forms. In other words, the fertilized egg contains a "master code" for life. Reproduction is the transfer of the coded instructions which direct the formation of the new organism. Living things pass to each generation a formula for continuing life.

Life is a continuous process.

In many organisms, tiny sperm and eggs are living "messengers" which unite to form a fertilized egg, the beginning of a new life. As "messengers," sperm and eggs link one generation to the next so that the process of life continues. Individual plants and animals die and many groups of organisms have become extinct, but life continues without interruption.

## 1:8 Organization

You have now looked at some ways in which energy is used by living things. Growth and development, maintenance and repair, and reproduction are all common functions of life which use energy. Although each has been discussed alone, all of them are ongoing processes in a living system. None of the functions of living things is isolated from the others.

Energy is needed for the parts of an organism to work together in an orderly way.

A common feature of organisms is their precise organization. **Organization** is the orderly functioning of a living system. It involves the coordination of all the complex processes and activities of an organism. Organization can only be maintained if energy is available. It is the main result of energy use. Without a steady supply of energy, organization soon disappears. What happens to an organism's organization once it dies? Why?

How is the degree of organization of your desk or locker related to the energy you expended in the organizing process?

Not only are the complex processes and activities of a living thing organized. Living things are physically organized also. An organism is composed of interworking parts which differ in complexity. Thus, scientists have defined levels of organization.

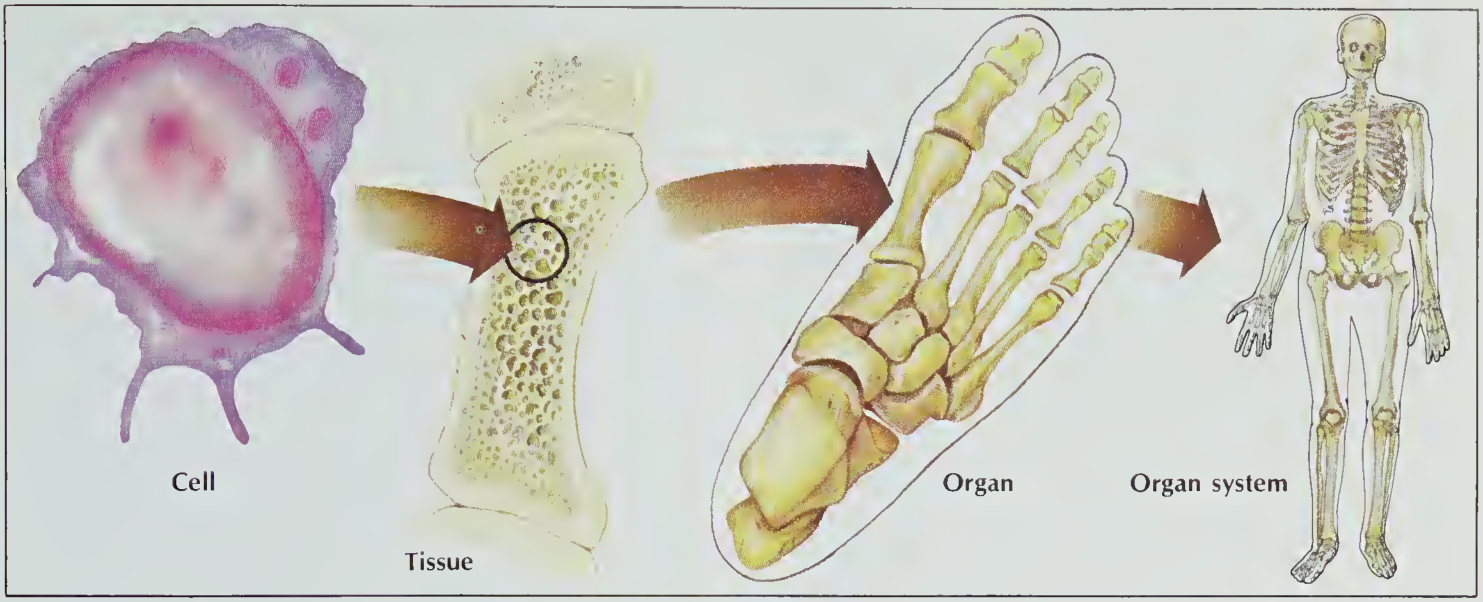


**FIGURE 1-10.** **Levels of biological organization include cells, tissues, organs, and organ systems.**

Most types of organisms are made of more than one kind of cell. You will study cells and their parts in Chapter 5. In organisms made of more than one kind of cell, similar cells are organized to do certain jobs. A group of cells having the same origin, structure, and function is called a **tissue.** Animal tissues include muscles, bones, skin, nerves, and blood. Plant tissues include protective areas such as bark and the outer surfaces of leaves, conductive tissue which transports water and food, and special regions of growth.

Groups of tissues are further organized into **organs.** The leaf of a plant, for example, is an organ of photosynthesis. It contains tissues for protection, water and mineral transport, food production, and transport of food. What are some other organs?

Biological levels of organization: cell, tissue, organ, system, organism.

A group of organs working together is known as a **system.** The stomach is an organ which is only part of the entire digestive system. What other organs work with the stomach? What are some other animal systems and some plant systems?

The total organism represents the next higher level of organization, but organism is not the end point. Life is more than individual organisms. Higher levels of organization, involving groups of organisms, also exist. For example, you have already learned about a community, which is composed of many kinds of organisms. Later you will learn about other ways in which organisms are grouped.

## REVIEWING YOUR IDEAS

8. What is development? How does it differ from growth?
9. Why are maintenance and repair important to living things?
10. What is reproduction? What is passed on to each generation?
11. List the levels of biological organization through organism.

# ORGANISM AND ENVIRONMENT

## 1:9 Adaptation

When you think about a community, you naturally think about the organisms living in it. A lake is inhabited by fish, snails, and algae. Cactus plants, scorpions, and lizards live in a desert. Crabs, jellyfish, and whales are found in the ocean. Deer, birds, and maple trees live in a forest.

Organisms are suited to particular environments.

Has it occurred to you that organisms are suited to particular kinds of environments? A fish has gills that obtain oxygen from the water. A deer has teeth that grind plant material. Birds have wings. A cactus stores water. Maple trees have broad leaves which trap sunlight in photosynthesis.

Adaptations promote survival.

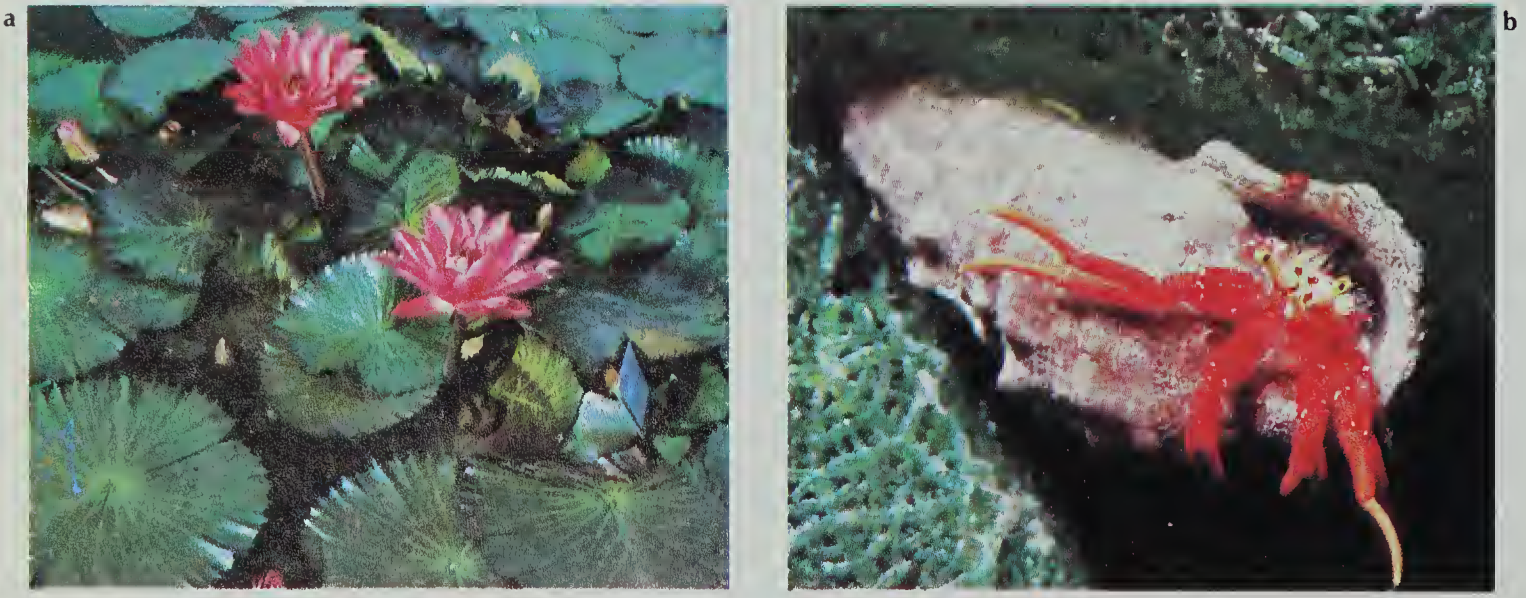
These special parts and activities of organisms are examples of adaptations. An **adaptation** is a feature of a living thing which enables it to survive in its environment. Adaptations are another common feature of living things. You will learn more about adaptations in Chapter 11.

## 1:10 Relationships Within the Environment

Ecology is the study of the relationship between organisms and their environment.

Each living thing is a complex organization of interacting parts. Without the proper working of all of its parts, the organism would be in trouble. So, too, the success of a community depends on the organisms in it. Living things do not exist alone; they live together and depend on each other. The study of the relationship between organisms and their environment is **ecology.** An ecologist wants to know how organisms live with each other and how they interact with the things around them.

**FIGURE 1-11. (a) Water lilies and (b) a hermit crab have special adaptations which aid their survival. What are some of their adaptations?**



Richard Brommer

Sharon Kurgis

Gene Frazier

Don Nieman

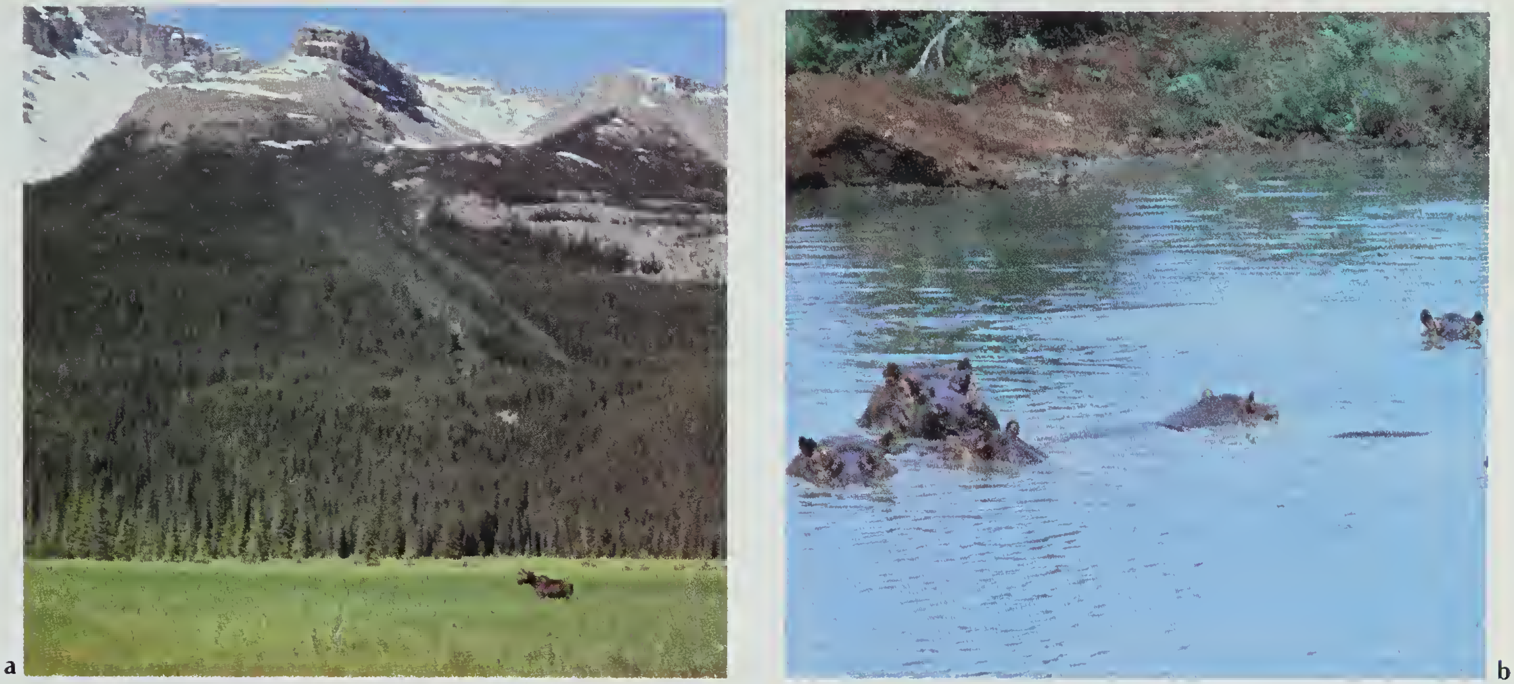


**FIGURE 1-12.** Physical factors of the environment determine the kinds of organisms that can live in different places. (a) Trees cannot grow above a certain altitude mainly due to colder temperatures. (b) Due to the amount of water, hippos can live in areas where certain other organisms cannot.

A study of a community reveals many ways in which plants and animals interact. Many birds build nests in trees and other plants. Bees transfer pollen from flower to flower. Seeds of some plants are transported in the fur of mammals. Molds may grow on rotting wood, and some insects live under the bark of trees. Many organisms require mates in order to reproduce, and many young organisms must be cared for by their parents. The predator and prey relationship (Section 1:4) is another way organisms depend on each other.

Organisms depend on one another in many ways.

Physical factors of the environment are also important to a community. Without water, carbon dioxide, and oxygen, most organisms could not live. The type of soil and amount of water determine the kinds of plants which can live and grow in a certain place. The amount of shade the plants provide affects temperature which in turn affects the kinds of plants and animals that can live there.

Physical factors of the environment determine the kinds of organisms living in a given community.

Can you see that a community, like an organism, is a well-organized system? Also, in nature the community is a feature of life because no organism, regardless of its adaptations and complexity, can exist by itself. In many ways humans depend on their environment. They also affect their environment in many ways. Explain. What do you think is the responsibility of humans concerning the environment?

## REVIEWING YOUR IDEAS

12. What is an adaptation? List three animal adaptations.
13. What does an ecologist want to find out about a community?
14. List several ways in which organisms depend on one another.

## CHAPTER REVIEW

### SUMMARY

1. The nearly two million kinds of known living things share certain common features.
2. Organisms live together in communities.
3. All organisms need food. Producers make their own food while consumers depend on other living things for food.
4. The energy in food comes from sunlight through photosynthesis. "Burning" of food transfers energy.
5. Materials in a community are recycled. Because energy is not recycled, a community must have a constant supply of energy.
6. Energy from the "burning" of food is used for growth and development, maintenance and repair, reproduction, and organization.
7. Scientists have defined several levels of organization to describe living things—cell, tissue, organ, system, organism, and community. Higher levels also exist.
8. Organisms are adapted for life in particular environments. Organisms also interact in and with their environments.

### LANGUAGE OF BIOLOGY

adaptation
biology
cellular respiration
chlorophyll
community
consumer
decomposer
development
ecology
energy
food chain
growth
heredity
homeostasis
host
organ
organism
organization
parasite
photosynthesis
predator
producer
reproduction
saprophyte
system
tissue

### CHECKING YOUR IDEAS

*On a separate paper, match each phrase from the left column with the proper term from the right column. Do not write in this book.*

1. necessary for decay process
2. balance of internal processes
3. released during photosynthesis
4. characteristic promoting survival
5. interaction of organisms and environment
6. increase in living material
7. obtains food from host
8. necessary for work
9. substance "burned" by all organisms
10. Like produces like.
11. tissues working together
12. makes own food

a. adaptation
b. decomposer
c. ecology
d. producer
e. energy
f. growth
g. homeostasis
h. organ
i. oxygen
j. parasite
k. reproduction
l. sugar

### EVALUATING YOUR IDEAS

1. Why is it difficult to define "life"? What is important to an understanding of "life"?
2. What are some similarities between an automobile engine and a living thing? What are some differences?
3. Distinguish between parasites and saprophytes. Are they producers or consumers?
4. What is energy? What is the source of energy in every community? How is it transferred to all members of a community? Is energy recyclable? Explain.
5. How are decomposers important to a community? What would happen to a community in which there were no decomposers? Why?

## CHAPTER REVIEW

6. How are photosynthesis and cellular respiration important to each other?
7. What is homeostasis? Why is it important to living things?
8. What is meant by the phrase "like produces like"? Why does it occur?
9. Why is it possible to say that the process of life is continuous?
10. What is meant by "organization" of living things?
11. What is a tissue? What is an organ? What is a system? List some examples of each.
12. What is an adaptation?
13. What are some physical factors of the environment?

## APPLYING YOUR IDEAS

1. List several types of communities. What do they have in common? How do they differ?
2. Indian pipe is classified as a green plant, but it lacks chlorophyll. Why is it able to survive on a forest floor better than green plants with chlorophyll?
3. Classify each of the following as a parasite or saprophyte.
   (a) tick on a dog
   (b) termites in dead wood
   (c) tapeworm in a cow
4. Give an example of a possible food chain in a lake and in a desert.
5. What would be the simplest possible food chain in a community? Explain.
6. A piece of potato immersed in water absorbs some of the water and swells. Has the potato grown? Explain.
7. How are availability of water, temperature, light, and type of soil important to a community?
8. List three adaptations of a tree. List three adaptations of a human. How do the adaptations you listed help the organism survive in its environment?
9. Why are there few producers at the bottom of a deep lake or ocean?

## EXTENDING YOUR IDEAS

1. Search the area near your home for different kinds of organisms. Classify each one as either producer or consumer. Identify any parasites or saprophytes you find. Determine how each organism fits into food chains of the community. List several adaptations of each organism.
2. Create your own miniature community by setting up a freshwater aquarium or a terrarium.
3. Make a list of five specific ways in which your body uses energy.

## SUGGESTED READINGS

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Donald R. Perry

*Biology is the branch of science in which living things are studied. To study something scientifically, a method must be followed and precise measurements must be made. Scientific research may be carried out both in the laboratory or in the field. Here a field biologist studies organisms living in the trees of the tropical rain forest. How is a scientific study done? What steps must be followed and what kinds of measurements are made?*

# Chapter 2

# BIOLOGY AS A SCIENCE

**GOAL:** You will gain an understanding of how a scientist conducts an investigation and how to use the International System of Measurement.

Humans have always wondered about themselves, other organisms, their world, and space. They have sought to explain things and to make use of what they learned.

Early biology centered on studies vital to human life. Thousands of years ago humans learned about planting crops and taming animals. They were also concerned with the body and with health. Later, humans became curious about things other than their own needs.

Many so-called "truths" remained untested until the sixteenth century when scientists began to experiment for themselves.

Rather than question ideas themselves, most people relied on the beliefs of earlier scientists. Some of these beliefs were not correct. Thus, progress in biology (and other sciences) was slow. This pattern lasted until the 1500's. Then important findings based on new observations and study began to be made.

During the late 1800's some important general discoveries about biology were made.

The late 1800's were an exciting time for biology. It was learned that all living things are made up of small units called cells, and that some cells called microbes can cause disease. It was shown that all life comes from life. The basic laws of heredity were discovered. These findings were important because they were general enough to apply to most organisms. Also, they provided a basis for later discoveries.

Today is an even more exciting time for biology. Diseases such as malaria and polio are now understood and can be prevented or treated. The structure of the "genetic message" has been worked out. Genes can be moved from one organism to another. Energy is being derived from many sources. Surgery now often includes the use of lasers. Crop yields are being improved. Computers are being used to gather, record, and analyze information.

Knowledge continues to grow at a rapid rate. Each year, new information is built on the foundation of prior knowledge. Much of this knowledge benefits humans and other organisms. How has science affected you personally?

# METHODS OF SCIENCE

## 2:1 What Is Science?

A scientist must be a good detective.

Early scientists did not know *how* to solve their problems. Often they did not study all the facts. Many times they did not know what they were looking for. One of the most important factors in good science is asking the right questions. Many discoveries made in the last few hundred years are valid because the scientists who made them were good detectives.

The *methods* by which science is studied are unique. A scientist is a detective who must solve problems by asking questions and putting the answers together in a meaningful and conclusive way. Intelligent guessing is important to the scientist. But guessing alone is not enough. The guesses must be supported or rejected by evidence.

Science differs from other areas of study in the methods used.

**Science** is a process which produces a body of knowledge about nature. Areas of study, such as art, music, or history, are no less scholarly than science because all of them involve creativity. But, the *manner* in which science studies nature makes it different.

Technology is the application of scientific knowledge in a practical way.

Science is carried out because people want to learn more about nature. Applying the knowledge to real problems is **technology** (or applied science). For example, the science of heredity can be used to solve real problems. Plants that make more food and organisms that break down oil have been produced. What practical problems have these technological advances helped to solve?

Scientists can solve problems in many ways. Each "case" is different. Usually certain parts such as observation, interpretation, hypothesis (hi PAHTH uh sus) formation, and experimentation are included. The relative place of each of these in scientific investigations may vary. However, they interact and are necessary in solving a problem.

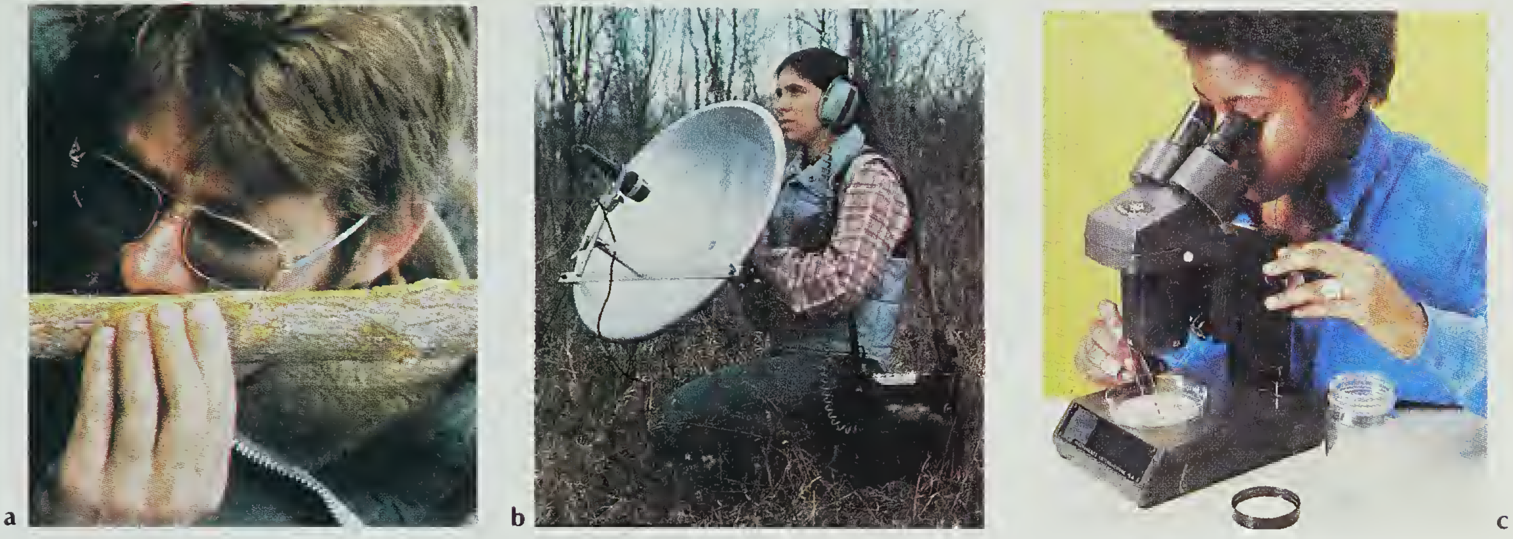
## 2:2 Observation

A scientist observes to determine what is fact.

Careful **observation** is very important to a scientist. No matter what the problem, scientists must observe carefully all they can about it. Often this process includes reading what is known already about the subject or related subjects. Careful and confirmed observations become facts. A **fact** is something about which there is no doubt. It is a fact that this paper is white.

Facts in science are called data (singular, datum).

In science facts are often called **data.** A list of the measurements of the growth of a tadpole is a set of data. Also, the color and shape of a tadpole are data.



James N. Westwater

David M. Dennis

Hickson-Bender Photography

**FIGURE 2-1.** Observations can be made with all of the senses. (a) A biologist identifies a tree by its smell. (b) Bird songs are observed by hearing and are recorded for study. (c) A student observes traits of a starfish visually.

Scientists must be careful not to overlook facts. They must know the importance of what they observe. Sometimes an observation may seem unimportant. However, it may end up being valuable.

In 1928, the British scientist Sir Alexander Fleming (1881-1955) made such an observation. He was studying a certain type of bacteria, *Staphylococcus* (staf loh KAHK us), in his laboratory. The bacteria were grown in culture dishes. Fleming noticed that a mold called *Penicillium* (pen uh SIHL ee um) grew in some of the culture dishes. He might have thrown out these dishes, but he observed something else. Around the *Penicillium* was a clear zone (Figure 2-2). This area was clear because the bacteria which had grown there had died. In dishes without the mold, no clear zone appeared because bacteria continued to grow and reproduce.

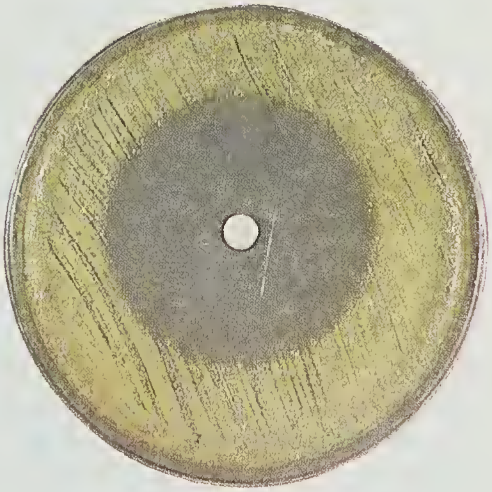
Fleming made an unexpected observation which was the basis of an important discovery.

## 2:3 Interpretation

This brief discussion of Fleming's discovery points out an important part of the scientific procedure. Observing that bacteria were killed, Fleming *reasoned* that the mold must be producing a substance, a chemical, which killed the bacteria. He *assumed* that the chemical moved from the mold throughout the clear zone. He could not observe a substance either being produced by the mold or killing the bacteria. But this idea was the most *logical* explanation he could make of the observed facts.

Such reasoning is a key part of scientists' investigations. They must be able to *interpret* their observations of nature. These interpretations and explanations may not always be correct. What may seem to be a logical explanation might turn out completely or partly wrong. Logical reasoning and interpretation are necessary to obtain a final answer to any scientific problem.

**FIGURE 2-2.** Penicillin from the soaked filter in the center of the dish produces a clear zone where no bacteria will grow. Notice the bacterial growth outside the clear zone.



C. Findel, J. Gnau, and A. Ottolenghi at O.S.U.

## 2:4 Hypothesis

Facts have no meaning unless they can be tied together. A scientist must try to put together the pieces as if working a jigsaw puzzle without knowing what the total picture will look like.

If a scientist gains insight into the problem, he/she will develop an idea which may fit the pieces of the puzzle together. Such an idea or statement is called a **hypothesis.** The purpose of a hypothesis is to relate and explain observed facts. Fleming's reasoning about the action of *Penicillium* on bacteria could be stated as a hypothesis. Fleming's hypothesis was that some chemical produced by the *Penicillium* kills certain bacteria.

A hypothesis relates and explains observations and predicts new facts.

A good hypothesis not only *explains* the facts but also *predicts* new facts. Besides stating that a chemical killed the bacteria, Fleming also predicted that the certain chemical *alone* (not the entire mold) should be able to kill bacteria.

Forming a hypothesis is not the end of the problem. Many early scientists failed because they made a hypothesis their conclusion. A good hypothesis must be tested. Only if there is a test can a scientist be certain a hypothesis is correct. A hypothesis is a "tool" for further study of a problem.

## 2:5 Experimentation

A hypothesis must lend itself to testing.

Experimentation is scientific testing.

Once a hypothesis has been presented, the next step is to test it. Such scientific testing is known as **experimentation.** You may have thought of experiments as involving smoking liquids in strange gadgets. Most experiments are fascinating but offer little of this type of excitement. Rather, they involve an orderly procedure and careful work. The excitement comes from finding a way to check a hypothesis.

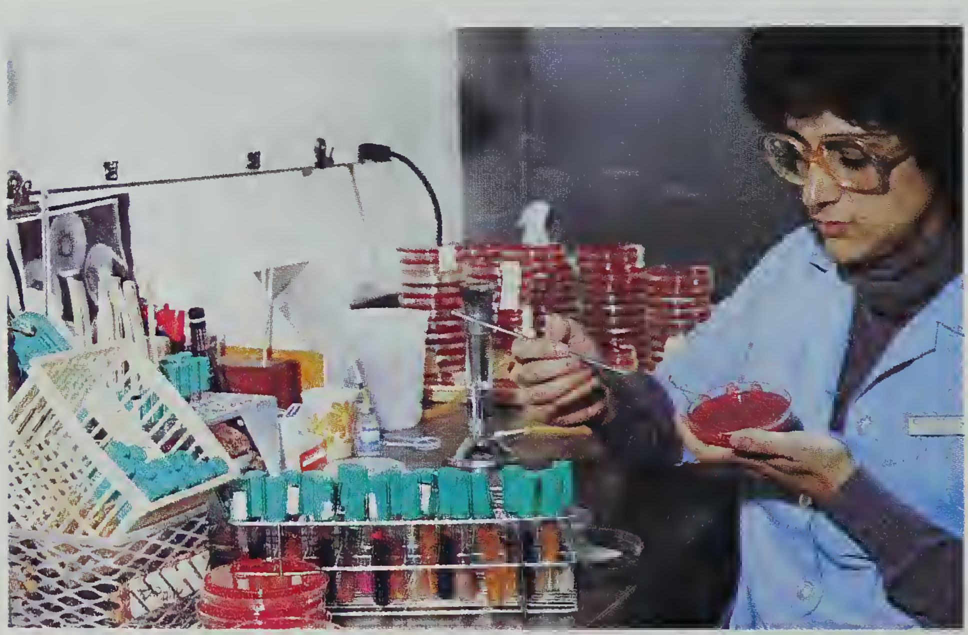


**FIGURE 2-3. Experimentation is done to test hypotheses. This scientist is testing a hypothesis about the growth requirements of certain bacteria.**

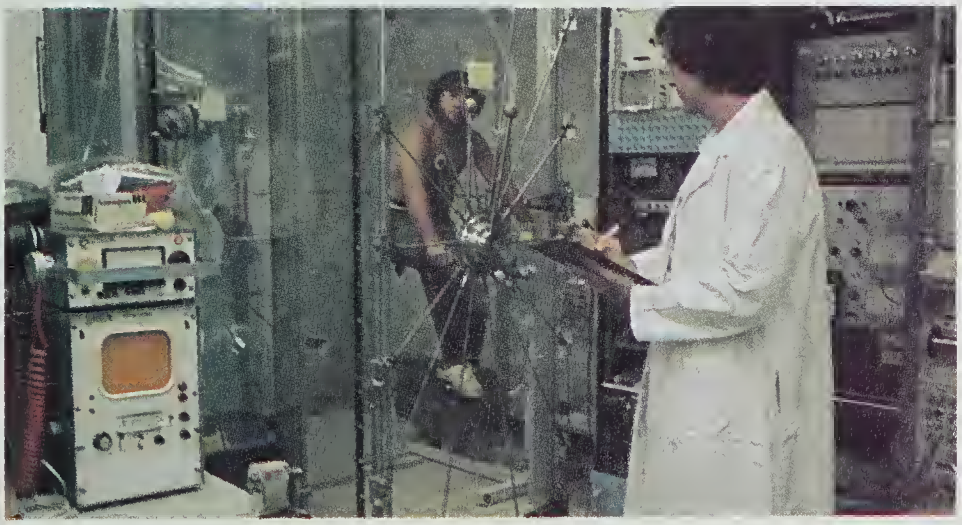
*Doug Martin*

Fleming had to isolate the substance he thought was killing the bacteria. Then he had to test the prediction that the substance would kill the bacteria. To do this test, he transferred some of the mold to nutrient broth solutions. Nutrient broth solutions contain the basic ingredients needed for the mold to grow and reproduce. Fleming assumed the mold would produce a chemical that would flow into the liquid broth. After he added the chemical and broth (minus the mold) to the bacteria, he observed that the bacteria were killed. Thus, he had isolated the chemical and also verified the prediction of his hypothesis. The chemical alone could kill the bacteria; the mold was not necessary. Has the hypothesis been verified beyond doubt?

A scientist must be sure of the cause of a certain effect. Fleming, for example, believed that the chemical in the broth killed the bacteria, but how could he be sure? Something in the broth itself might have killed the bacteria. When a test of the broth alone showed that it did not kill the bacteria, the doubt was removed. The hypothesis was supported. Fleming named the chemical *penicillin*.

Scientists conduct their experiments in a carefully controlled manner. A **controlled experiment** is one in which all factors are the same except the one being tested. The factor being tested is called the **variable factor.** Suppose you were testing a substance suspected of killing bacteria. You would have to run a controlled experiment to verify your idea. You would need two groups of bacteria which would be the same in all ways except that one would be exposed to the new substance and the other would not. Thus, the substance is the variable factor between the two groups. The group which received the chemical is the **experimental group;** the other group is the **control group.** Use of controls and using only one variable factor at a time are common features of scientific investigation because they reduce uncertainty.

Scientists carry out controlled experiments in which there is only one variable factor.



Tom Stack for Tom Stack and Associates

FIGURE 2-4. In this controlled experiment the man inside the chamber is undergoing a stress test in polluted air. The polluted air is the variable factor. All other factors are controlled.

An experiment may indicate that a hypothesis is not correct. If so, a scientist, like a detective, must either revise or develop a new hypothesis to explain the facts.

An experiment does not always support a hypothesis. Instead, it may show that the hypothesis was partly or totally wrong. When this result happens, the facts must be looked at again and interpreted in some other way. The hypothesis may need to be changed or a new hypothesis may need to be formed. The whole process may have to be repeated many times before a hypothesis is confirmed.

Fleming's work with penicillin arose by chance during other research and led to a major *practical* breakthrough. Fleming realized the future use of penicillin as a drug and studied its effect on many common disease-causing bacteria. Penicillin's discovery has caused a search for similar drugs. Many drugs have been discovered since that time which kill bacteria. These drugs, now called **antibiotics,** have been a great aid to modern medicine. Although many people take antibiotics for granted, it's not surprising that they were once called miracle drugs. Their use has saved millions of lives.

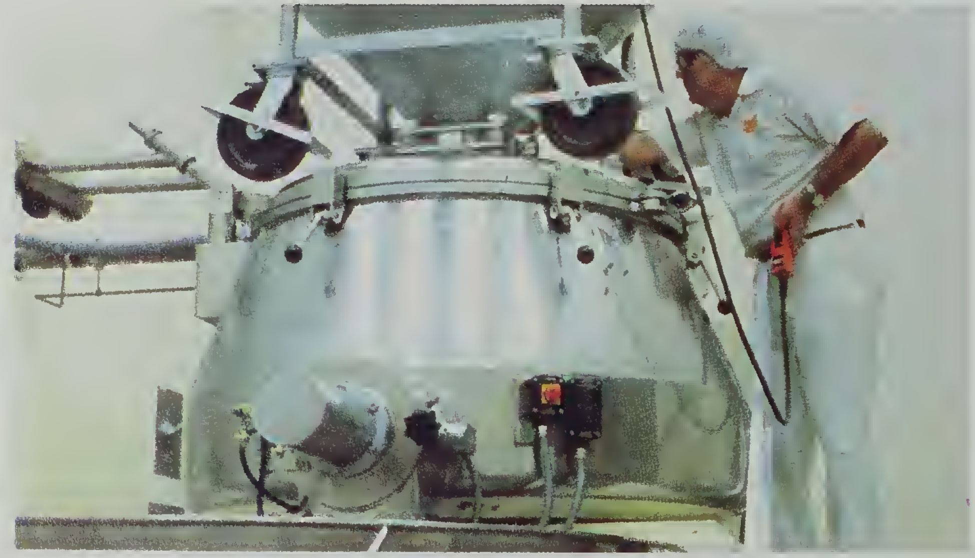
antibiotic (anti-, against; bio-, life)

This example illustrates two important points. First, much scientific research is carried on because of the natural curiosity of humans. They want to know the "hows" and "whys" of the world. As a result, there have been many benefits, from microwave ovens to antibiotic drugs. Fleming did not set out to discover a drug to cure bacterial infections, but when the unexpected happened, he did not ignore it. Use of the drug in medicine came about only after he made his "accidental" discovery.

Many practical benefits result from the natural curiosity of scientists.

Second, scientific knowledge builds upon the foundations of previous findings. Once penicillin was discovered and its value shown, widespread interest arose. A single, important finding led to many related discoveries. This pattern has been repeated often in the history of science—an important hypothesis provides a basis for further work.

Science builds upon previous knowledge.



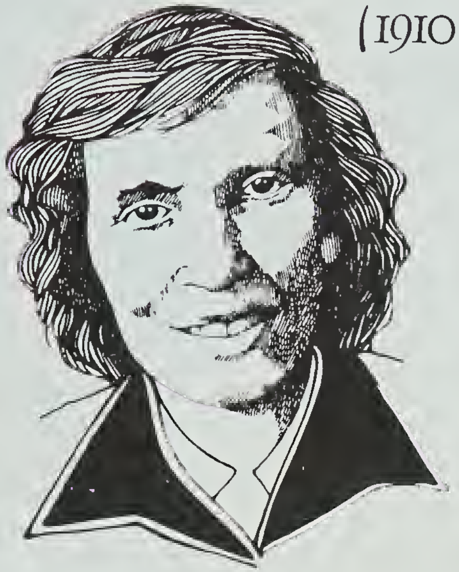
Courtesy of Eli Lilly and Co.

**FIGURE 2-5. Antibiotics are a great aid to modern medicine and are now mass-produced. This man is working with an antibiotic granulator.**

# PEOPLE IN BIOLOGY

About the time of Fleming's discovery of penicillin, Dorothy Crowfoot was becoming interested in a then new technique called X-ray crystallography (krihs tuh LAHG ruh fee). This technique involves the use of X rays to determine the structure of substances.

In 1937, Hodgkin received her doctorate from Oxford University in England where she continued X-ray research begun as a student. During World War II, the demand for penicillin became great. Penicillin could be made in large amounts if its structure were determined. Hodgkin set a goal to determine this structure. By 1948 she accomplished this goal. Through her work and that of her research team, the foundation was laid for mass production of antibiotics.



(1910 - )

Dorothy Crowfoot Hodgkin

Among other accomplishments, Hodgkin has determined the structure of vitamin $B_{12}$ and insulin. She has received many honors, including honorary degrees, the Royal Medal, and the Order of Merit. In 1964 she received the Nobel Prize in Chemistry for her contributions to biochemistry and medicine.

Hodgkin has three children and is now a grandmother, also. She lives in England with her husband and still works in her research lab in Oxford.

## 2:6 Theory

Scientists tend to shy away from the word "proof" in describing experimental results. It is possible that new data will cause revision of an accepted hypothesis.

In general, when a major hypothesis has survived testing, it is called a **theory.** Common usage of the word suggests an uncertainty, such as, "This is only a theory, but . . ." The opposite meaning is true in science. A theory is as close to a complete explanation as science has to offer and can be used to predict future outcomes.

All scientific theories are subject to revision and further analysis. New findings can alter an accepted explanation of observed facts.

### REVIEWING YOUR IDEAS

1. Compare science to other areas of study.
2. What is a fact? What are data?
3. What elements are necessary for interpretation?
4. What are the functions of a hypothesis?
5. What is a controlled experiment? Why is it necessary?

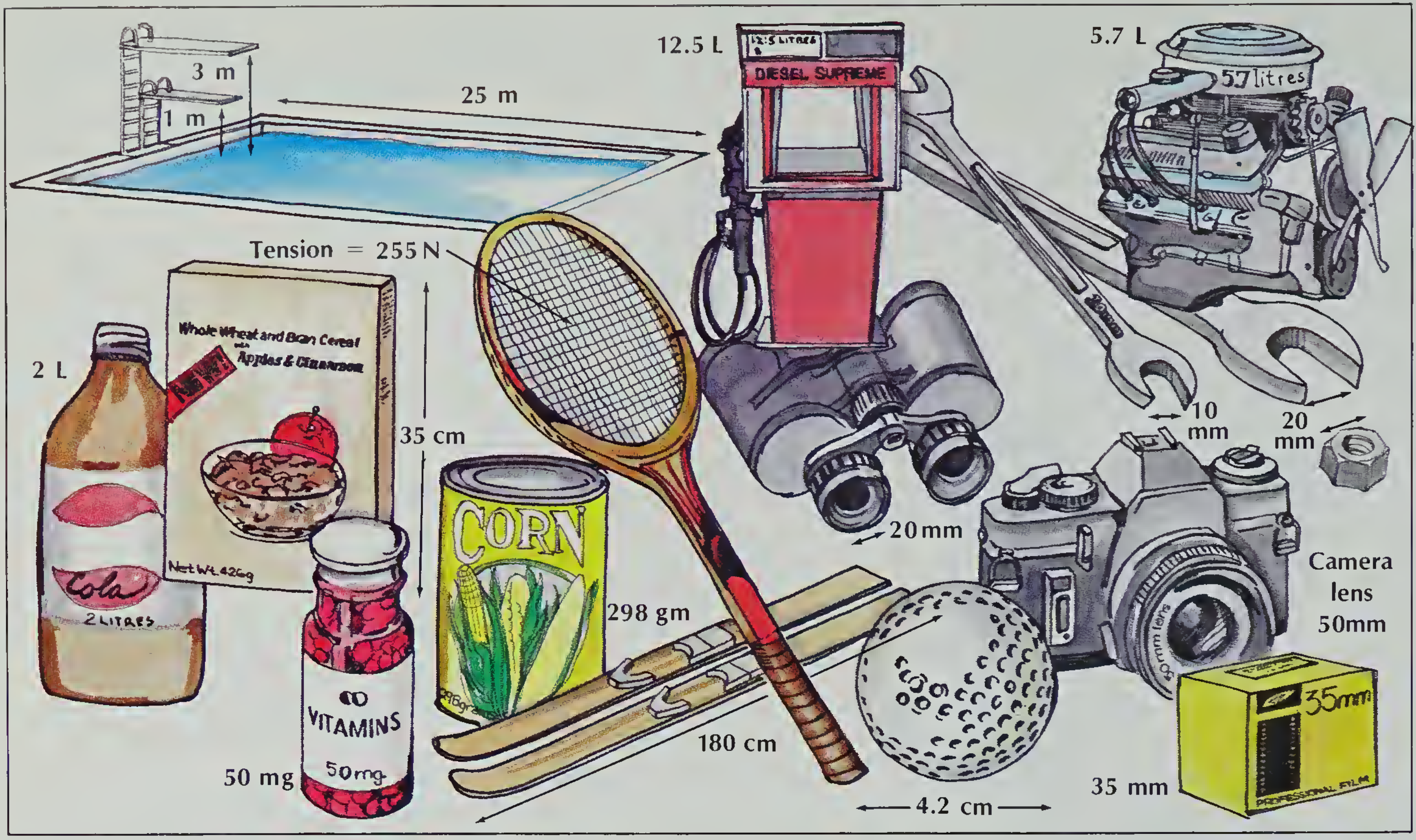

3 m
1 m
25 m
12.5 L
DIESEL SUPREME
5.7 L
5.7 litres
Tension = 255 N
2 L
Whole Wheat and Bran Cereal
Apples & Cinnamon
Net Wt. 426g
Cola
2 LITRES
35 cm
CORN
298 gm
10 mm
20 mm
20 mm
Camera lens 50mm
VITAMINS
50mg
50 mg
180 cm
4.2 cm
35 mm
35mm
PROFESSIONAL FILM

**FIGURE 2-6. Measurements of many common items are made in SI units.**

## SCIENCE AND MEASUREMENT

## 2:7 International System

SI is a universal system of measurement.

Because science is a worldwide study, discoveries made in one place are important to scientists around the world. The transfer of information is hindered by the many languages in the world. There is no special language in which to record and publish findings. Thus, reports must be translated in foreign journals to inform scientists worldwide of progress made. However, there is a special language of measurements and their symbols, the **International System of Measurement (SI).** SI is a modern form of the older metric system and is now used in most countries. What are some other advantages of converting to the International System of Measurement?

SI is based on tens and multiples or fractions of tens.

SI measurements may seem a bit foreign to you when you begin using them. However, you will soon see that there are advantages to using SI. One major advantage is that SI is a decimal system. It is based on tens, multiples of tens, and fractions of tens. Because it is a decimal system, SI is much easier to use. You need to know only a few major points. Did you ever stop to think that the English system of measurement is a lot less practical?

## 2:8 Linear Measurement

The basic unit of length in SI measurements is the **metre** (m). One metre is about as long as a golf club. The height of most doorways in a home is about 2 m. In SI, any measurement of length contains the word "metre." Measurements of lengths smaller or greater than a metre are indicated by a prefix and the word "metre." Each prefix stands for a multiple or a fraction of ten. The SI prefixes most important to you in this course are indicated in Table 2-1. According to this system, one hundredth of a metre is one centimetre, and a kilometre equals one thousand metres. What is a millimetre?

Length is expressed in metres in SI.

Prefixes are used to indicate fractions or multiples of each SI unit.

**TABLE 2-1. IMPORTANT SI PREFIXES**

| Prefix | Symbol | Meaning | Multiply basic unit by |
|---|---|---|---|
| kilo | k | one thousand | 1000 |
| centi | c | one hundredth | 0.01 |
| milli | m | one thousandth | 0.001 |
| micro | μ | one millionth | 0.000 001 |
| nano | n | one billionth | 0.000 000 001 |

Biologists often use the smaller units for microscopic work. The most common of these is the **micrometre** (μm) which is a unit of length equal to 0.001 mm or 0.000 001 m. Smaller measurements are recorded in nanometres. A **nanometre** (nm) is equal to 0.001 μm or 0.000 000 001 m. These measurements are commonly used to measure cells and cell parts.

The micrometre and nanometre are important in microscopic work.

Areas can be calculated using SI measurements. A rectangle measuring 5 cm by 3 cm has an area of fifteen centimetres squared (15 $cm^2$). What is the area of this rectangle in millimetres squared? Metres squared?

## 2:9 Volume

Units for solid volumes come from linear measurements. The measurements are cubed for volumes. For example, solid volumes can be expressed in centimetres cubed ($cm^3$). A cube measuring two centimetres on each side has a volume of eight centimetres cubed. Express this amount in millimetres cubed ($mm^3$).

SI units of area and volume are derived from the metre.

Units for liquid and gas volumes come from linear measurements, too. One cubic centimetre equals one millilitre (mL). One thousand millilitres equals a **litre** (L), a unit for liquid or gas volumes. Scientists often work with small volumes, so use of the millilitre (or cubic centimetre) is common.

The litre is the basic SI unit for liquid and gas volumes.

NASA

**FIGURE 2-7.** Astronauts experience weightlessness at certain places in space.

## 2:10 Weight and Mass

Weight is the measure of gravitational attraction between two objects.

Suppose astronauts were to weigh an object before lifting off in a space shuttle and then weigh the same object again at various distances from the earth. They would find a decrease in **weight,** a measure of gravitational attraction between two objects. As the shuttle reaches a point where the earth has very little attraction for the object, the object (and the astronauts) would become essentially weightless. Its weight would be very small.

Mass is the measure of the amount of material in an object.

Before leaving Earth, suppose the astronauts measured the amount of material in the object. This measurement, called **mass,** would have been constant throughout their voyage.

Weight not only varies in space. Because points on Earth are not exactly the same distance from Earth's center, there are differences in the weight of an object on the earth at different places.

Mass remains constant. However, weight varies with the size of and distance between objects.

Mass and weight are often confused because many people incorrectly regard them as equal. *Mass is the amount of material of which something is composed. It does not change with location. Weight is a measure of gravitational attraction between two objects and varies with size of and distance between the objects.*

The basic unit of mass in SI is the **kilogram** (kg). One kilogram equals 1000 g. The mass of two paper clips is about one gram. The same set of prefixes applies to this unit of measure as applies to the metre. Therefore, mass can be measured in units such as milligrams (mg) and micrograms (μg).

A scale is used to measure weight. Mass is measured by using an instrument called a **balance.** The object being massed is compared to an object of known mass, called a standard, on the balance.

*National Bureau of Standards*

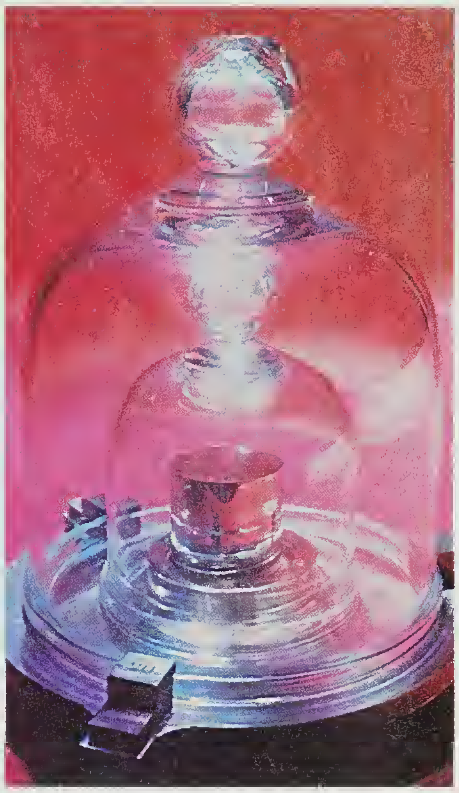


**FIGURE 2-8.** Standards such as this kilogram mass are maintained by the National Bureau of Standards in Washington, DC, and by the International Bureau of Weights and Measures in Sèvres, France.

## 2:11 Temperature and Time

Most scientists use the **Celsius** (SEL see us) scale to measure temperature. On this scale, the freezing point of water is zero degrees, and the boiling point is one hundred degrees. The temperature often is given in weather reports in degrees Celsius.

Another measurement important to scientists is time. The basic unit of time in SI is the **second** (s). SI prefixes are often used for very short time periods. For example, a millisecond is one thousandth of a second. Such exact measurements have become common in the study of some biological processes.

Some people have suggested changing the minute, hour, and day to new units based on multiples of ten. Do you think this should be done? Why or why not? What problems might the change cause?

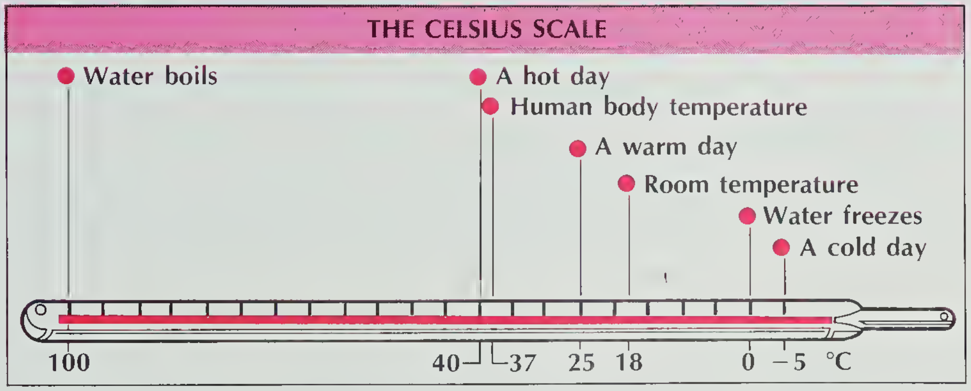


**FIGURE 2-9.** The Celsius scale is used for scientific measurements of temperature. Some common temperatures are shown here.

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### REVIEWING YOUR IDEAS

6. What are some advantages of the International System of Measurement?
7. List the prefixes most commonly used with SI units. What does each prefix represent?
8. In SI, what is the basic or accepted unit of length? Mass? Volume? Time?
9. What are the freezing and boiling points of water on the Celsius scale?

Camera M. D. Studios, Inc.

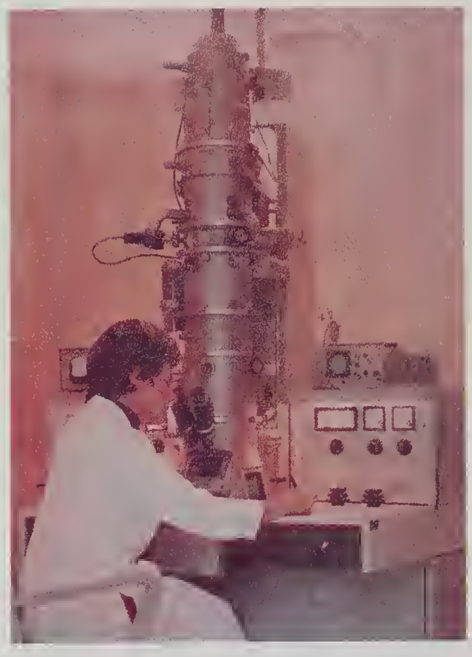


**FIGURE 2-10. The electron microscope is a valuable tool in many fields of biology.**

A microscope's resolving power is its capability to distinguish two objects as separate.

ADVANCES IN BIOLOGY

## 2:12 Electron Microscopy

Observation is a key part of any scientific work. It is especially important to a biologist. Because the biologist may study extremely small objects—a tiny organism or the parts of a cell—observation often requires tools which magnify.

During your course in biology, you will use a compound light microscope. It works because light passes through the object being examined and is focused by glass lenses. Your microscope will magnify things about 450 times. The highest powered light microscopes can magnify as much as 2000 times. You could see a bacterium with the light microscope, but you could see little of its outer structure and none of its inner structure. Not only is magnification important, but resolving power also determines what can be seen with a microscope. **Resolving power** is the ability to distinguish two objects as two separate things. The resolving power of a light microscope is about 500 nm. Two objects closer together than 500 nm will be seen as one object with the light microscope.

For greater magnification and resolving power, many biologists rely on **electron microscopes.** Although electron microscopes are not new, their use has become increasingly important in many areas of biology. Electron microscopes typically magnify hundreds of thousands of times. The resolving power is about 0.5 nm. Two main types, the **transmission electron microscope (TEM)** and the **scanning electron microscope (SEM)**, are used in modern research.

With the TEM, the sample to be studied is frozen and then sliced into very thin sections. Thus, living specimens cannot be

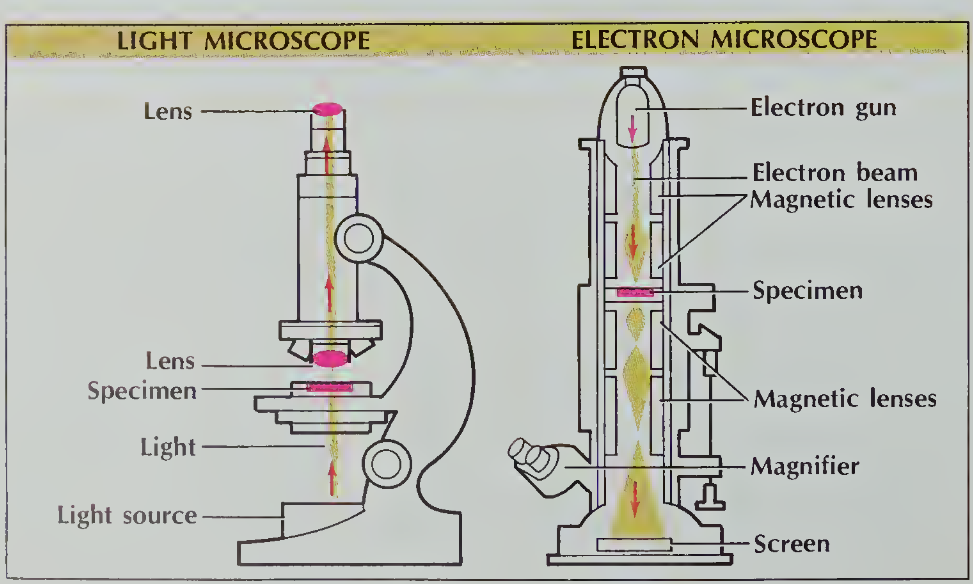
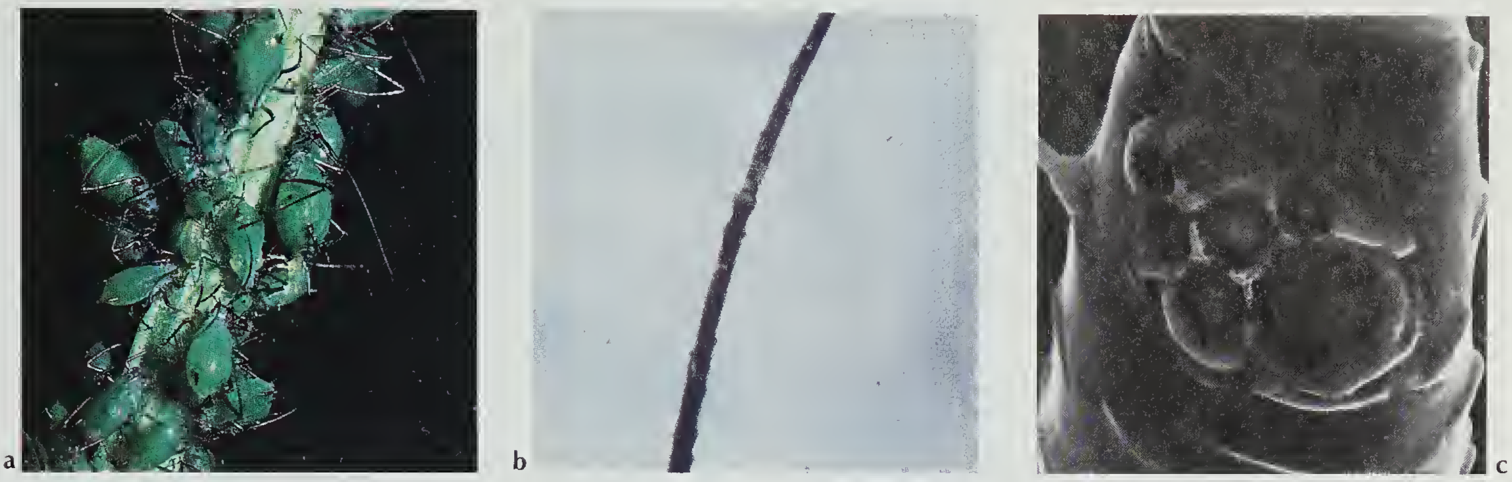


**FIGURE 2-11. Both the light microscope and the electron microscope direct a beam through a specimen, focus it with lenses, and enlarge the final image. They differ in that the light microscope focuses a beam of light with glass lenses whereas the electron microscope focuses a beam of electrons with magnets.**



Hans Pfletschinger for Peter Arnold

David M. Dennis

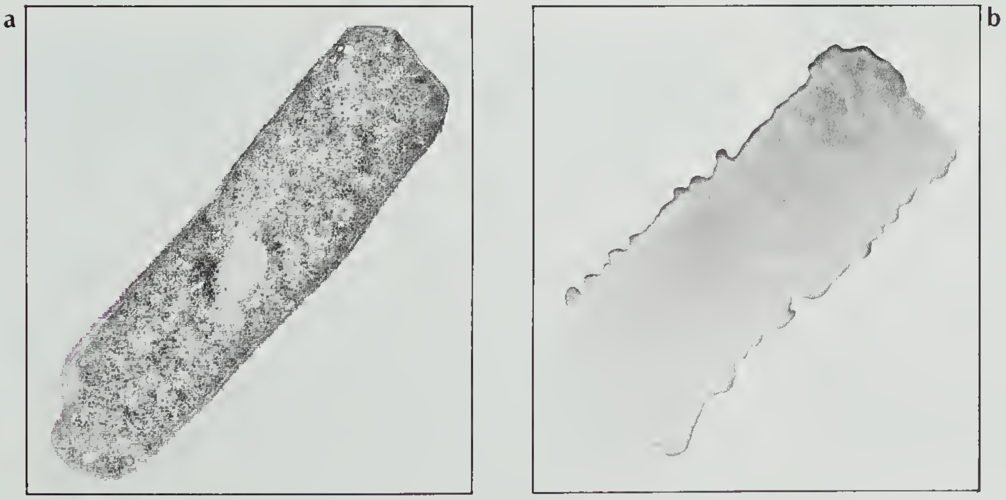
David Scharf for Peter Arnold

**FIGURE 2-12.** (a) Aphids are small insects which can be seen with the unaided eye. Details of an aphid can be seen by use of microscopes. (b) The antenna can be seen enlarged with the light microscope and (c) sensors on the antenna can be seen with the electron microscope.

viewed; only parts of structures can be seen. When the sample is put in the microscope, a beam of electrons passes through it. Focusing is done with magnets instead of glass lenses. The electrons form an image that can be seen on a screen. Photos of the sample also can be made. The TEM is very important in the study of the structures inside cells. It reveals fine details that aid in understanding how cells and cell parts function.

The SEM permits a view of surfaces not possible with the TEM. Although the SEM does not magnify as much as the TEM, the SEM produces a three-dimensional (3-D) image. Thin sections are not required because the beam of electrons does not pass through the specimen. Instead, the beam sweeps across and bounces off the object, causing electrons to be knocked loose from the object. These electrons produce light and dark patterns. An image is formed on a televisionlike screen. Because thin sections are not used, living organisms can be viewed and details about their surfaces can be learned. Knowledge of the surfaces of cells, for example, is important in studying cancer and other diseases. Interactions of cells with each other and with chemicals can be studied with the SEM.

The SEM produces a three-dimensional view of living specimens.



John Hanson/OSU

John Hanson/OSU

**FIGURE 2-13.** (a) The transmission electron microscope shows an image, in this case of a bacterial cell, that is two-dimensional. (b) The same kind of cell has a three-dimensional image when seen with the scanning electron microscope. Both cells are shown enlarged about 22 000 times.

# CHAPTER REVIEW

## SUMMARY

1. An interest in themselves and their world led humans to study nature.
2. Early attempts at science often were unsuccessful because inaccurate observations and poor logic were used. Untested conclusions were made.
3. Modern methods of science have been responsible for the vast new wealth of scientific information.
4. Scientific investigation usually includes observation, interpretation, hypothesis formation, and experimentation.
5. A controlled experiment is used to determine whether or not a hypothesis is correct. The experimental group is compared to the control group.
6. Scientists all over the world use the International System of Measurement, a system based on multiples of ten.
7. SI units include the metre (length), kilogram (mass), litre (liquid volume), Celsius degree (temperature), and second (time).
8. Biology as a science has advanced greatly due to the use of microscopes. Electron microscopes have yielded much information about the structure and functions of organisms and their parts.

## LANGUAGE OF BIOLOGY

Celsius
controlled experiment
data
experimentation
hypothesis
International System of Measurement
kilogram
litre
mass
metre
observation
resolving power
scanning electron microscope (SEM)
second
technology
theory
transmission electron microscope (TEM)
variable factor
weight

## CHECKING YOUR IDEAS

*On a separate paper, complete each of the following statements with the missing terms. Do not write in this book.*

1. A statement explaining and relating facts is called a(n) ______.
2. SI measurements are based on fractions or multiples of ______.
3. A controlled experiment has only one ______ factor.
4. In SI, the basic unit for length is the ______.
5. Applied science is also called ______.
6. One litre equals ______ millilitres.
7. ______ is the amount of material of which something is composed.
8. A major hypothesis which withstands the "test of time" is called a(n) ______.
9. Information gathered during an experiment is recorded. These recorded facts are also called ______.
10. The ______ electron microscope is used to view the surfaces of cells.
11. The ______ of a microscope is the closest two points can be and still be seen as separate.
12. Zero degrees is the temperature at which water freezes on the ______ scale.

## EVALUATING YOUR IDEAS

1. Why did some of the unconfirmed conclusions of early scientists prevail for more than a thousand years?
2. List some of the major biological discoveries made since the late 1800's.
3. What makes a hypothesis good? Is a good hypothesis necessarily correct? Explain.
4. What hypothesis did Fleming attempt to test? How did he test it? What precautions

did he take to make certain that his hypothesis was correct?

5. What benefits were derived from Fleming's work? What point does this illustrate about science?
6. Why do scientists prefer not to use the word "proof"?
7. The millilitre and cubic centimetre are both units of volume. How do they differ?
8. What is the difference between weight and mass?
9. Express 50 cm in (a) metres and (b) millimetres.
10. Express 1.5 kg in (a) grams, (b) milligrams, and (c) micrograms.
11. Express 8 mL in litres. Express 800 L in millilitres.
12. Express the sum of 1.20 km + 844 mm + 125 cm in (a) metres, (b) centimetres, (c) millimetres, and (d) kilometres.
13. Express the sum of 2.2 L + 176 mL + 250 μL in (a) litres, (b) millilitres, and (c) microlitres.
14. List some differences in light microscopes and electron microscopes.
15. Describe the purpose for which the TEM and SEM are used.
16. Distinguish between magnification and resolving power.

## APPLYING YOUR IDEAS

1. How would you conduct an experiment to test the hypothesis that the rate of photosynthesis increases as the amount of available light increases?
2. How would you conduct an experiment to test a new dog food for "dog appeal"?
3. What would happen to your weight as you climbed a mountain? What would happen to your mass? Are dieters really trying to lose weight or mass?
4. The micrometre and nanometre are units of linear measurement. Why are these units important to some biologists?

## EXTENDING YOUR IDEAS

1. Prepare a report on several kinds of antibiotics. Include in your report the names of the organisms from which the antibiotics are prepared and the diseases against which they are useful.
2. Many molds growing in soil have antibiotic properties. Collect soil samples from different areas and place them on agar in different culture dishes. Transfer to agar plates on which bacteria are growing the different molds which appear. Determine whether any of these molds produce antibiotics.

## SUGGESTED READINGS

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George Hunter/fpg

*Bicycles are assembled from many different, separate parts. The bicycle parts were made by processes that changed their shape and composition. The changes were both physical and chemical. In the same way, living things are composed of many different substances that go through similar physical and chemical changes. What are the different substances of which living things are made? How are the substances like those that form nonliving things?*

Chapter

3

# MATERIALS OF LIFE

For a long time biology was just a description of living things. Organisms were grouped and named by their features. Early biologists were curious about the **anatomy** (study of internal and external structure) of organisms. They then became curious about *how* the parts worked. Study of how living things work is known as **physiology** (fihz ee AHL uh jee). The beating of the heart and the flowering of a plant are examples of physiological processes. How does a nerve transmit an impulse? What causes a muscle to contract? How are minerals moved from the roots of trees to the leaves?

**GOAL:** You will gain an understanding of how chemistry relates to the study of living things.

Physiology is the study of the functions of living things.

Biologists realized that knowledge of chemistry and physics was needed because living things shared many features with nonliving things. Some principles about matter and its properties are presented in this chapter. Knowledge of these principles is needed for an understanding of many biological functions.

An understanding of the properties of matter is needed for the study of physiology.

## CLASSIFICATION OF MATTER

### 3:1 Atoms

**Matter** is anything which has mass and takes up space. All matter is composed of building blocks called **atoms.** Atoms are very small, most of them being from 0.1 to 0.5 nm in diameter. Today only the most powerful microscopes can photograph individual atoms. Much detail still cannot be seen.

Matter has mass and takes up space.

Brookhaven National Laboratory

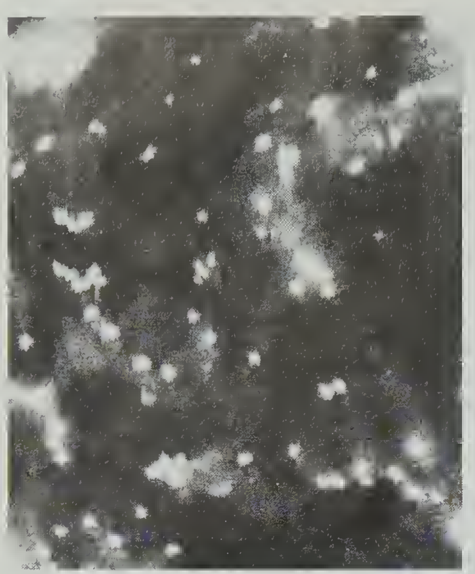


**FIGURE 3-1. Because atoms are so small, not much detail can be seen in photographs of them. Uranium atoms are shown here magnified about 5.5 million times.**

Electrons form electron clouds around the nucleus of an atom. Some electrons are farther from the nucleus than others.

Different energy levels, when filled, have different numbers of electrons.

Atoms are composed of three major particles—protons, neutrons, and electrons. **Protons** and **neutrons** are bunched tightly together in the center to form the **nucleus** of an atom. Moving rapidly outside this nucleus are **electrons.** Protons are 57 positively charged, neutrons have no charge, and electrons are negatively charged. Electrons are sometimes indicated as e⁻. In an atom, the number of protons equals the number of electrons. H Therefore, the atom as a whole is neutral, has no electric charge.

Diagrams have been drawn based on information gathered He about atoms. A diagram of an atom is just another way of showing [illegible] its parts. Such diagrams show protons and neutrons as tightly packed particles at the center of the atom. Electrons move about the nucleus at certain *probable* distances from the center. The space which electrons fill forms an electron cloud around the nucleus. The **electron cloud** represents the space around the nucleus which the electrons *can occupy.*

Hydrogen, with one proton and one electron, is the simplest atom. A helium atom has two protons, two electrons, and two neutrons. In a helium atom, the two electrons are about the same distance from the nucleus. Lithium (Figure 3-2) has three electrons per atom. One of the electrons is usually farther from the nucleus than the other two.

The different regions in which electrons travel about the nucleus are called **energy levels.** The first energy level holds a maximum of two electrons. The second energy level has a maximum of eight electrons, and the third energy level has eighteen electrons. Aluminum (Figure 3-2) has thirteen electrons per atom. Electrons of each aluminum atom would usually be arranged as follows: two in the first level, eight in the second level, and three in the third level. How would electrons be arranged in an atom with seven electrons? Eighteen electrons?

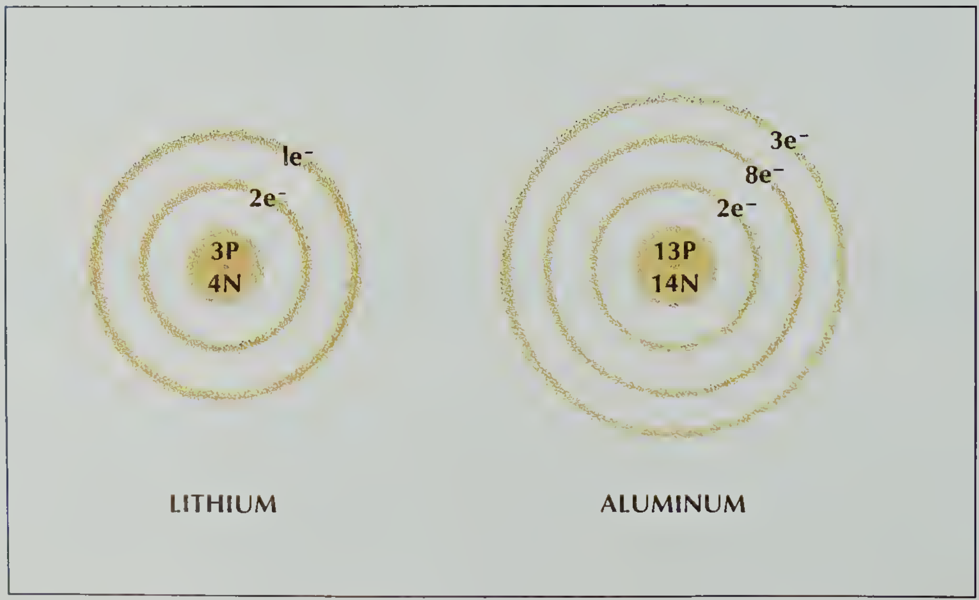


**FIGURE 3-2. Diagrams of a lithium atom and an aluminum atom show the energy levels at which electrons move around the nuclei of the atoms. The best description of the probable location of electrons in an atom is an electron cloud.**

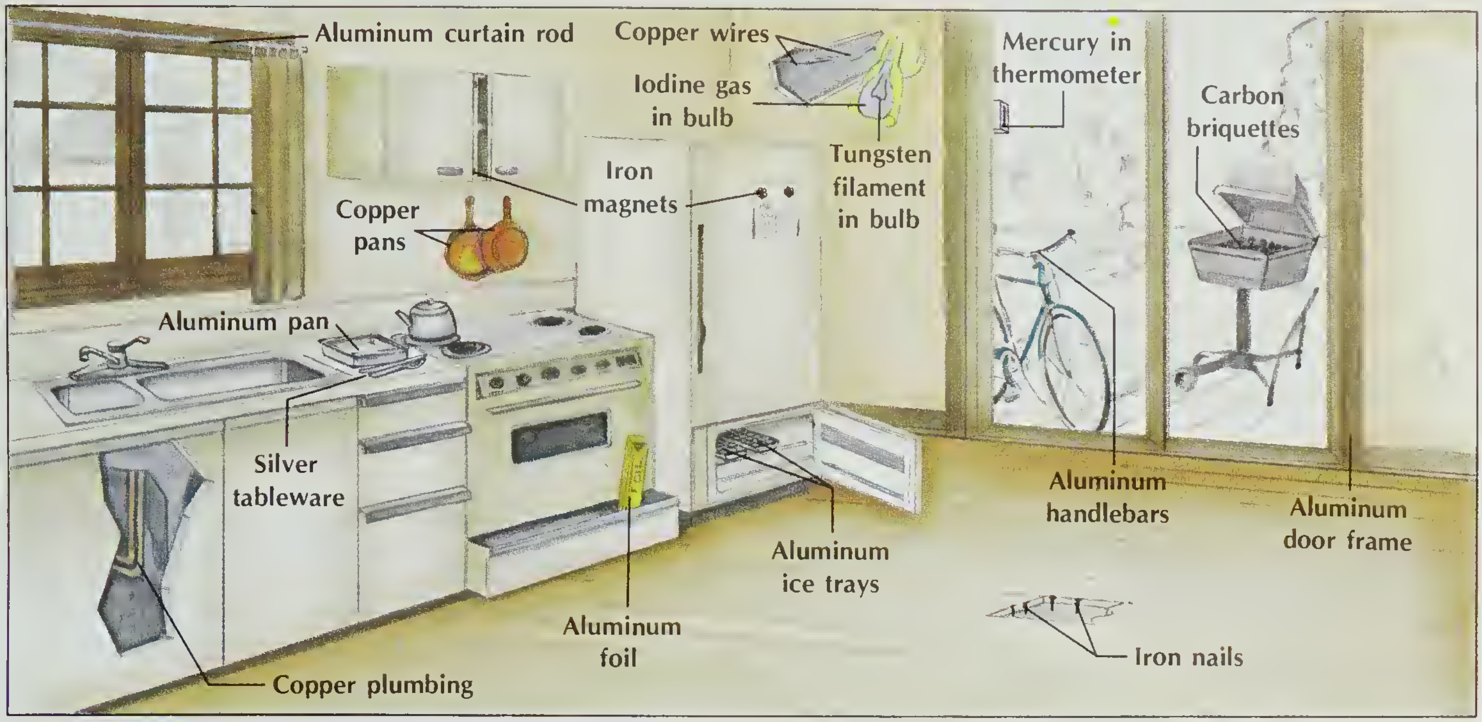

Aluminum curtain rod
Copper wires
Iodine gas in bulb
Mercury in thermometer
Carbon briquettes
Tungsten filament in bulb
Iron magnets
Copper pans
Aluminum pan
Silver tableware
Aluminum handlebars
Aluminum door frame
Aluminum ice trays
Aluminum foil
Iron nails
Copper plumbing
FOIL

**FIGURE 3-3.** Many common objects are composed of one element each.

## 3:2 Elements

Hydrogen, helium, lithium, and aluminum are all **elements,** substances composed of only one type of atom. The number of protons in the nucleus determines the type of atom. For example, a piece of copper has only copper atoms. Each atom has the same number of protons, 29. Each iron atom has 26.

All atoms of a given element have the same number of protons in their nuclei.

Any given proton, neutron, or electron in a substance is the same as in any other substance. The combination of these particles makes one kind of atom different from another. All copper atoms are identical to one another in the number of protons and electrons. But iron atoms differ from copper atoms in the number of protons and electrons each type has.

Atoms of the same element can differ in their number of neutrons. Such atoms are called **isotopes** (ɪ suh tohps) of each other. Atoms of hydrogen usually contain no neutrons, but one isotope (heavy hydrogen) has one neutron, and another isotope (heavy, heavy hydrogen) has two neutrons. All three isotopes of hydrogen have one proton and one electron.

Isotopes are atoms which differ from other atoms of the same element only in the number of neutrons in their nuclei.

### REVIEWING YOUR IDEAS

1. What is matter? Of what is matter composed?
2. List the three major kinds of particles of an atom. Where is each located and what is its charge?
3. Why does a free atom have no electric charge?
4. What is an element? What is an isotope?

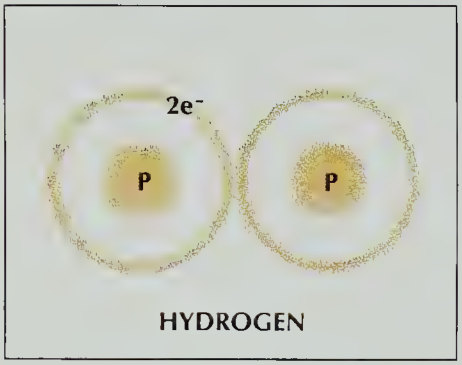
## 3:3 Molecules

Although only eighty-eight elements exist naturally, there are thousands of different substances. Atoms combine with one another to form different substances. Often two or more atoms of the same element are combined. For example, the hydrogen atom never occurs alone in nature. It always combines with other atoms, including other hydrogen atoms.

When simple atoms combine, their outer energy levels acquire an outer octet of electrons.

*Most atoms combine in such a way that their outer energy levels acquire a total of eight electrons.* This principle is called the **octet rule.** (In the case of atoms with only one energy level, that energy level acquires a total of two electrons—the **duet rule.** For example, a hydrogen atom has only one electron in its outer level. In combining with other atoms, it must acquire one more electron.) An atom of nitrogen has five electrons in its outer level. When it combines with other atoms, it must acquire three more electrons.

**FIGURE 3-4. Two hydrogen atoms join to form a hydrogen molecule by sharing electrons.**



Two hydrogen atoms can join by *sharing* their electrons (Figure 3-4) so that each hydrogen atom has two electrons in its outer energy level. When this sharing occurs, the electrons occupy the space between and around the two nuclei.

Atoms which have joined are held together by forces called *chemical bonds*. The forces involved in the sharing of electrons, such as between hydrogen atoms, are known as **covalent** (koh VAY lunt) **bonds.** Such a combination of two or more atoms joined by a covalent bond is called a **molecule.**

## 3:4 Compounds

Suppose you had a small, covered bottle of hydrogen gas (hydrogen molecules). The air in the room would contain oxygen molecules. Because the bottle is covered, the hydrogen and oxygen molecules cannot meet. If you removed the cover, oxygen would enter the bottle and mix with the hydrogen, but nothing would happen. However, if an outside source of energy is applied, drops of water would form on the inside of the bottle (Figure 3-5). What has happened?

Energy increases the force of collisions between particles.

The energy increased the force of collisions between the two kinds of molecules. Bonds between the atoms in hydrogen molecules and between the atoms in oxygen molecules broke. The atoms then recombined to form water.

In order to combine to form water, each hydrogen atom must obtain one electron, and each oxygen atom requires two electrons. The duet and octet rules are obeyed when two hydrogen atoms combine with one oxygen atom. Each hydrogen atom *shares* its electron with an oxygen atom. Thus, the oxygen atom gains the two electrons it needs—one from each hydrogen

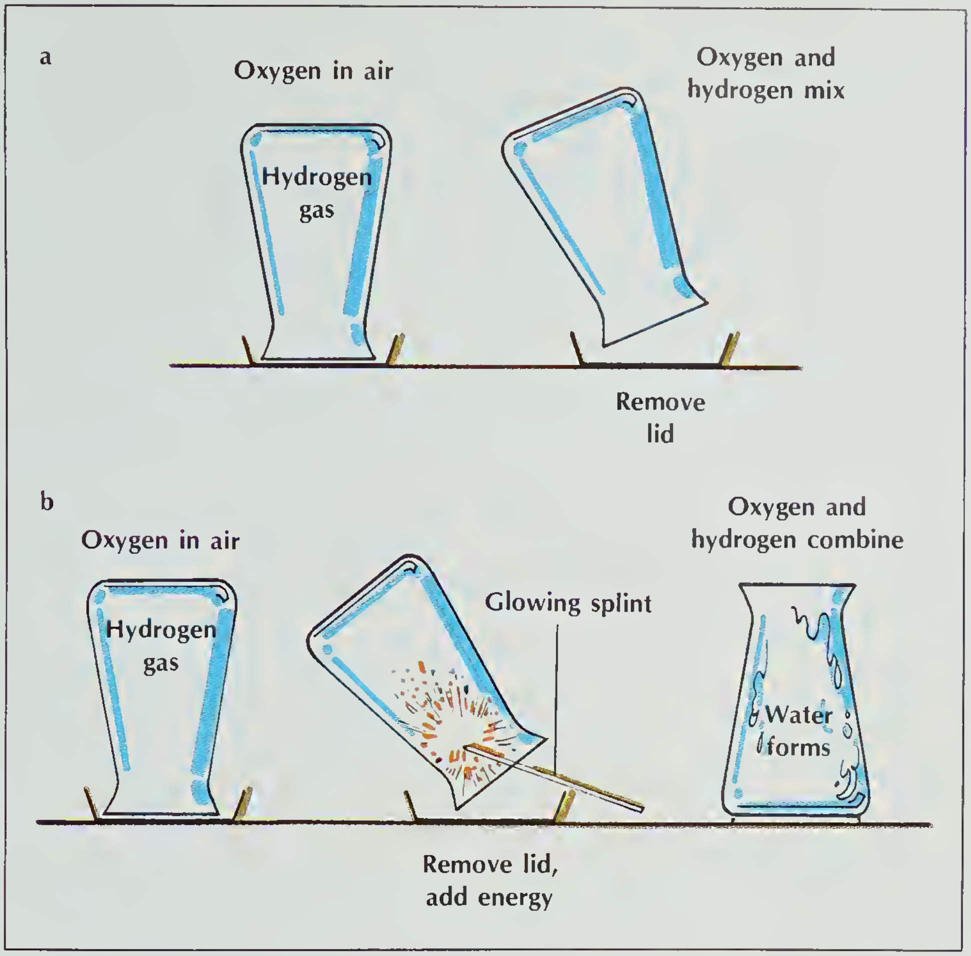

a
Oxygen in air
Hydrogen gas
Oxygen and hydrogen mix
Remove lid
b
Oxygen in air
Hydrogen gas
Glowing splint
Oxygen and hydrogen combine
Water forms
Remove lid, add energy

**FIGURE 3-5.** (a) Hydrogen and oxygen mix when no energy source is added. (b) With an added energy source, hydrogen and oxygen combine to form water.

atom. Each hydrogen atom obtains its needed electron by sharing electrons with the oxygen atom. Thus, each atom obtains its required number of electrons by sharing. As a result, the atoms join to form a new substance. Because the bond is formed by sharing of electrons, it is a covalent bond.

In water, covalent bonds exist between hydrogen and oxygen atoms.

This combination of two hydrogen atoms and one oxygen atom is also a molecule, a molecule of water. Water, salt, and sugar are substances made of two or more kinds of atoms. Substances composed of different kinds of atoms are known as **compounds.**

When atoms combine with one another, the new substances formed have a definite composition. A molecule of hydrogen always contains two hydrogen atoms. Water molecules always consist of two hydrogen atoms and one oxygen atom. Definite composition is explained by the octet or duet rule.

Biologists and biochemists are interested in the chemical reactions that occur in living things. Many of these reactions involve the synthesis (making) of compounds from atoms of other compounds or elements. The properties and processes of living things depend on the structures and reactions of compounds.

**FIGURE 3-6.** A water molecule is formed and outer energy levels are filled when two hydrogen atoms and one oxygen atom share electrons.

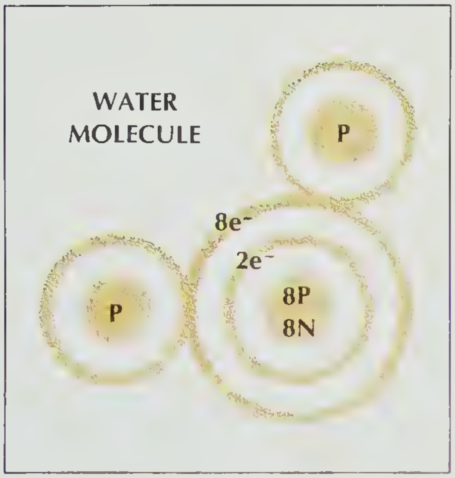
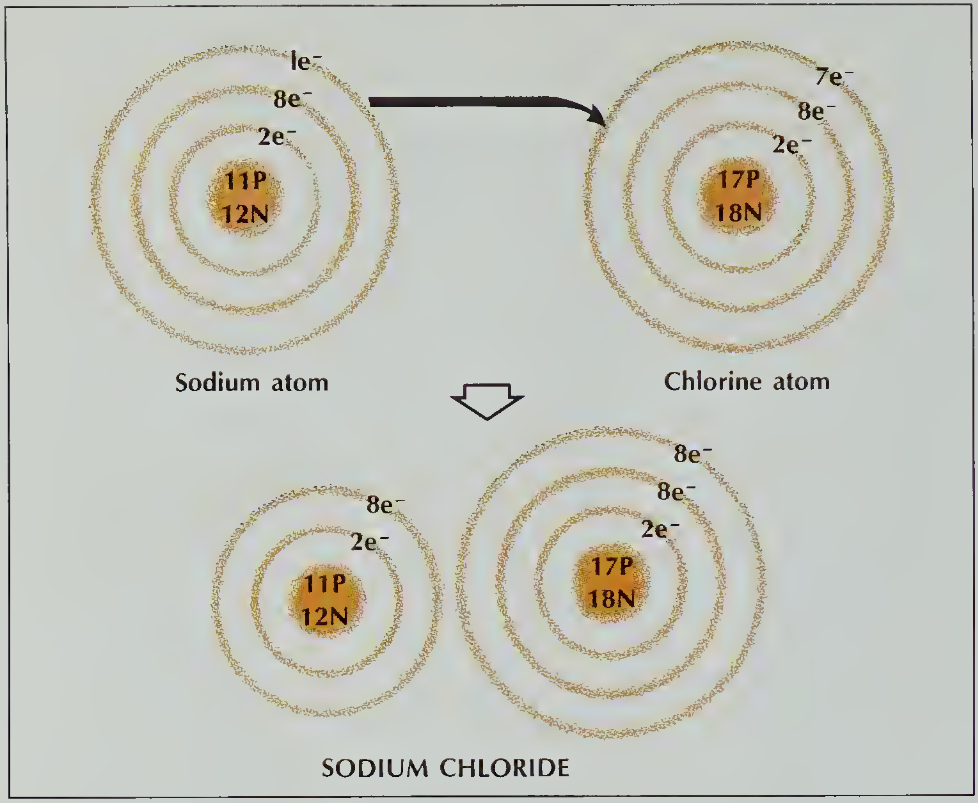

WATER MOLECULE
P
8e⁻
2e⁻
P
8P
8N

FIGURE 3-7. Sodium chloride forms when one electron is transferred from a sodium atom to a chlorine atom. The outer energy levels of both atoms are filled in this way.



## 3:5 Ions

Some chemical bonds form by the transfer of electrons.

Sometimes electrons are *transferred* to form an outer octet or duet of electrons. Compounds can be formed as a result of electrons being added or taken away from atoms. Two simple atoms, sodium and chlorine, can combine in this way (Figure 3-7). They combine to form the compound sodium chloride which is better known as table salt. A sodium atom has eleven electrons—two in the first energy level, eight in the second, and only one in its outer energy level. The outer level could be filled by "picking up" seven electrons or by "giving up" its one outer electron. Either way would give it an outer octet. A chlorine atom has seventeen electrons—two in the first energy level, eight in the second, and seven in the third. Because the atom has seven electrons in its outer energy level, it needs only one more. As sodium and chlorine atoms combine, each sodium atom "gives up" one electron which is "picked up" by a chlorine atom. In this way, each atom obtains an outer octet of electrons.

Ions are charged atoms or groups of atoms.

A loss or gain of electrons results in an unbalanced electric charge on an atom. Because a sodium atom has eleven positively charged protons and ten negatively charged electrons after losing an electron, it is positive by one charge, 1+. After gaining an electron, a charged chlorine atom has an excess of one negative charge, 1−. Such charged atoms are known as **ions** (ɪ ahnz). The electrons of each ion move about the nucleus of that ion.

Because sodium and chloride ions are oppositely charged, they attract each other. The attraction between ions is called an **ionic bond.** The number and kind of charge on each ion determine the composition of a compound. In order for a compound to form ionic bonds, the positive and negative charges must balance each other so the net charge is zero. Because sodium ions have a 1+ charge and chloride ions have a 1− charge, one of each ion gives a neutral compound. How would ions with a 2+ charge combine with ions with a 1− charge? Could two positive ions combine?

Instead of being called molecules, compounds of ions are called **ionic compounds.** Water is composed of water molecules in which each molecule contains two hydrogen atoms and one oxygen atom. However, a crystal of salt is made of a continuous network of alternating sodium and chloride ions. These ions are not paired with each other (Figure 3-8) to form a molecule. Salt is an ionic compound.

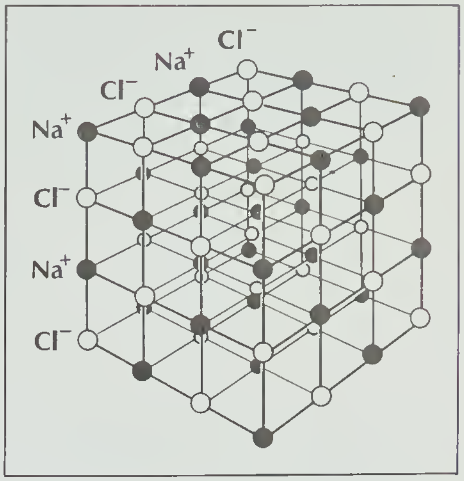


**FIGURE 3-8.** Ionic compounds do not exist as individual molecules. Salt, for example, is a crystal of alternating sodium and chloride ions.

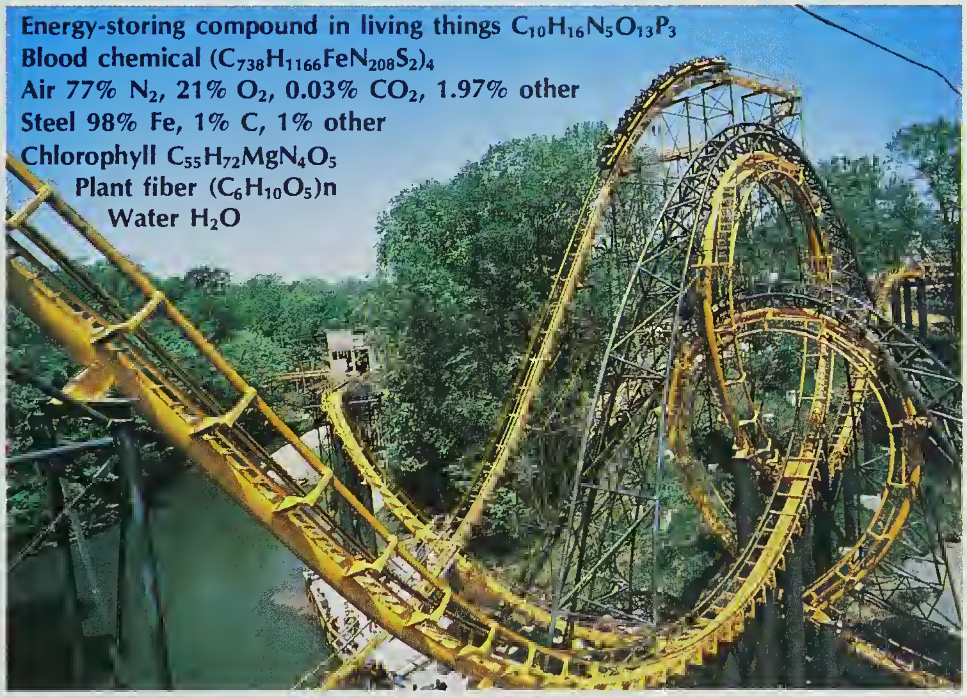
Ionic compounds are composed of positive and negative ions, not molecules (as in covalent compounds).

## 3:6 Symbols and Formulas

Chemists have developed a shorthand system for representing elements. Each element is given a **symbol** agreed on by all scientists. This symbol consists of either one or two letters. Hydrogen has the symbol H, iron is Fe, and copper is Cu. Notice that when a symbol contains two letters, the second is not capitalized. In addition to hydrogen, the elements most commonly found in living systems are carbon (C), oxygen (O), and nitrogen (N). A list of the chemical symbols is included in Appendix D.

Each element can be represented by a symbol of one or two letters.

Carbon, hydrogen, oxygen, and nitrogen are the elements most abundant in organisms.


Energy-storing compound in living things $C_{10}H_{16}N_5O_{13}P_3$
Blood chemical $(C_{738}H_{1166}FeN_{208}S_2)_4$
Air 77% $N_2$, 21% $O_2$, 0.03% $CO_2$, 1.97% other
Steel 98% Fe, 1% C, 1% other
Chlorophyll $C_{55}H_{72}MgN_4O_5$
Plant fiber $(C_6H_{10}O_5)n$
Water $H_2O$

Joseph F. Vieste/fpg

**FIGURE 3-9.** Chemical formulas can be written using chemical symbols for the atoms in the compounds and mixtures. Formulas of some of the items in this photo are shown. Those things that can vary in composition are written as percents.

Chemical formulas represent the number and kind of each atom in a compound.

A group of symbols, called a **chemical formula,** is used to show the number and kind of each atom in a compound. A molecule of water is composed of two hydrogen atoms and one oxygen atom. The chemical formula of water is $H_2O$. The subscript 2 refers to the element it follows. **Subscripts** in a formula represent the number of atoms of the element. When a symbol is not followed by a number, it is understood to represent one atom or ion.

In sodium chloride, the simplest ratio is one sodium ion to one chloride ion. Its formula is written NaCl. Notice that no subscripts are written because only one of each ion is involved.

A number before a chemical formula indicates the number of molecules or ionic units of a compound.

The formulas $H_2O$ and NaCl represent one molecule of water and one unit of salt. Five water molecules would be indicated by a number in front of the formula. It would be written $5H_2O$.

How many atoms are there in $5H_2O$? The 5 refers to the entire molecule, $H_2O$. Thus, there are 5 times 2 atoms of hydrogen and 5 times 1 atom of oxygen. The total atoms in $5H_2O$ is $10 + 5 = 15$. How many atoms are there in 3NaCl?

Chemists determine formulas by analyzing substances in the laboratory. Some formulas are listed in Appendix D. You do not need to learn many formulas in this course, but you should remember that the formula of a compound is determined by the bonding requirements of its atoms. Each compound has a definite composition which does not vary. You will be seeing formulas of biological substances throughout your study of biology.

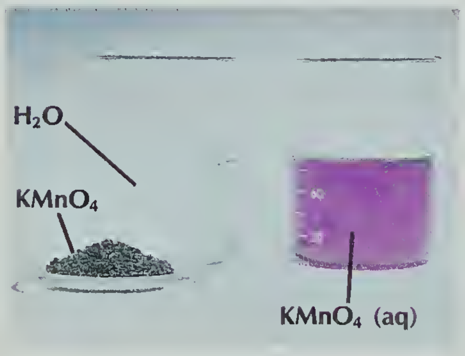
Chemical formulas are determined by the bonding requirements of the atoms of which the compound is composed.

## 3:7 Solutions

A homogeneous substance is the same throughout.

Hydrogen molecules and compounds, such as water and salt, are examples of homogeneous (hoh muh JEE nee us) substances. **Homogeneous** means the same throughout. In a glass of water, each water molecule is the same as every other water molecule.

**FIGURE 3-10. Potassium permanganate, $KMn0_4$, is a solute which can be dissolved in water, a solvent. An aqueous (water) solution of potassium permanganate results.**



*Hickson-Bender Photography*

Compounds such as water are homogeneous materials with a definite composition. The composition is definite because chemical bonds form in definite ways. Thus, certain atoms can combine only in specific ways.

Some homogeneous materials do not have a definite composition. These materials are formed as a result of a physical combination of substances. Suppose you dissolved one gram of sugar (a compound) in 100 mL of water (a compound). You would obtain a material which would be the same throughout. It would be homogeneous. If you added two grams of sugar to another 100 mL of water, you would again get a homogeneous material. The two materials would be the same, sugar water, but they would differ in composition. The second sample would contain a greater amount of sugar in the same amount of water.

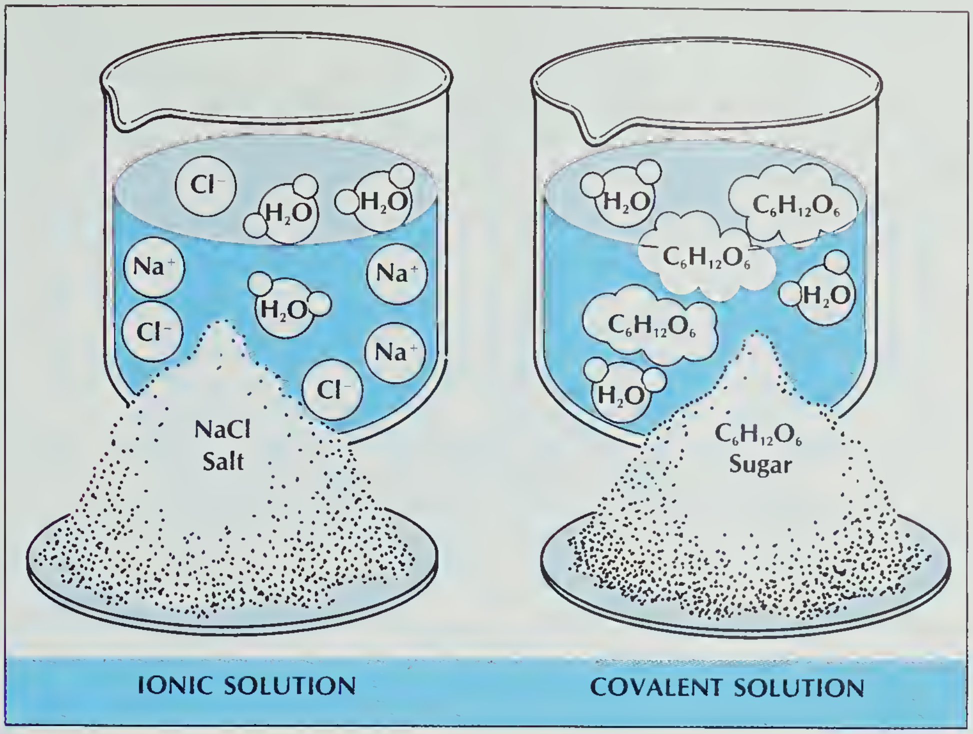


**FIGURE 3-11.** In solution ionic compounds, such as salt, dissociate into ions. Covalent compounds, such as sugar, dissolve as separate molecules.

This type of homogeneous material is called a **solution.** True solutions are homogeneous, but they have variable compositions depending on how much of one substance is dissolved in the other. The portion of a solution in greater quantity is called the **solvent** (SAHL vunt); the part in lesser quantity is the **solute** (SAHL yewt). In the example, the solute, sugar, was dissolved in the solvent, water. In a water-alcohol solution in which there is more alcohol present than water, the alcohol is the solvent and the water is the solute.

A solution is a homogeneous substance which can have different compositions.

A solute dissolves in a solvent.

Because sugar is a covalent compound, the sugar molecules separate when sugar crystals dissolve in water. The sugar molecules become dispersed (scattered) equally throughout the solvent. Ionic compounds do not behave in this way because they are not composed of molecules. When salt dissolves in water, the sodium and chloride ions separate by a process called **dissociation.** As a result, sodium and chloride ions move independently through the water. Therefore, a solution of sodium chloride in water consists of water molecules, sodium ions, and chloride ions (Figure 3-11).

Covalent compounds dissolve as separate molecules.

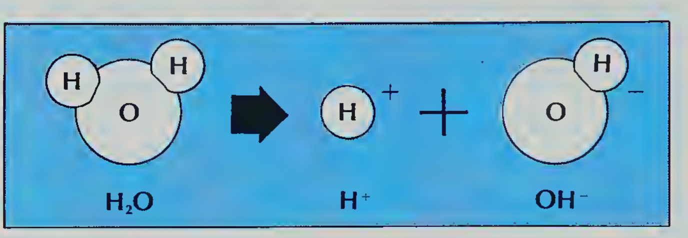
When ionic compounds dissolve, their ions separate and move independently in the solution.

Water is an excellent solvent. Because organisms are composed of about seventy percent water, dissociation of ionic compounds within living systems is common. Also, many ions which enter an organism are dissolved in water. Ions are important in many biological processes. For example, sodium ($Na^+$) and potassium ($K^+$) are essential to nerve conduction. Other ions are involved in processes such as muscle contraction. Ions are also parts of bone, blood, and other tissues.

Water is an important solvent in living things.

## 3:8 Acids and Bases

Each water molecule contains two hydrogen atoms and one oxygen atom. Very rarely (about two molecules per billion) one hydrogen atom breaks away from the rest of a molecule. The formation of a positively charged hydrogen ion ($H^+$) and a negatively charged hydroxide ion ($OH^-$) results.



In a neutral solution, the hydrogen ions and hydroxide ions are equal in number.

Therefore, in a given volume of water, most of the water exists as water molecules, but there are some hydrogen ions and some hydroxide ions. The number of hydrogen and hydroxide ions is equal because one of each kind of ion is produced from each water molecule that dissociates. A solution, such as pure water, in which the number of hydrogen ions equals the number of hydroxide ions is a **neutral solution.**

In an acid solution, the number of hydrogen ions is greater than the number of hydroxide ions.

Hydrogen chloride is a gaseous compound which dissolves in water to form hydrogen ions and chloride ions. Addition of hydrogen chloride increases the number of hydrogen ions in the water (Figure 3-12). If the number of hydrogen ions is greater than the number of hydroxide ions, the solution is called an **acid.** A solution of hydrogen chloride in water is called hydrochloric acid. Acid solutions have a sour taste. Lemons and grapefruit are sour because they contain citric acid.

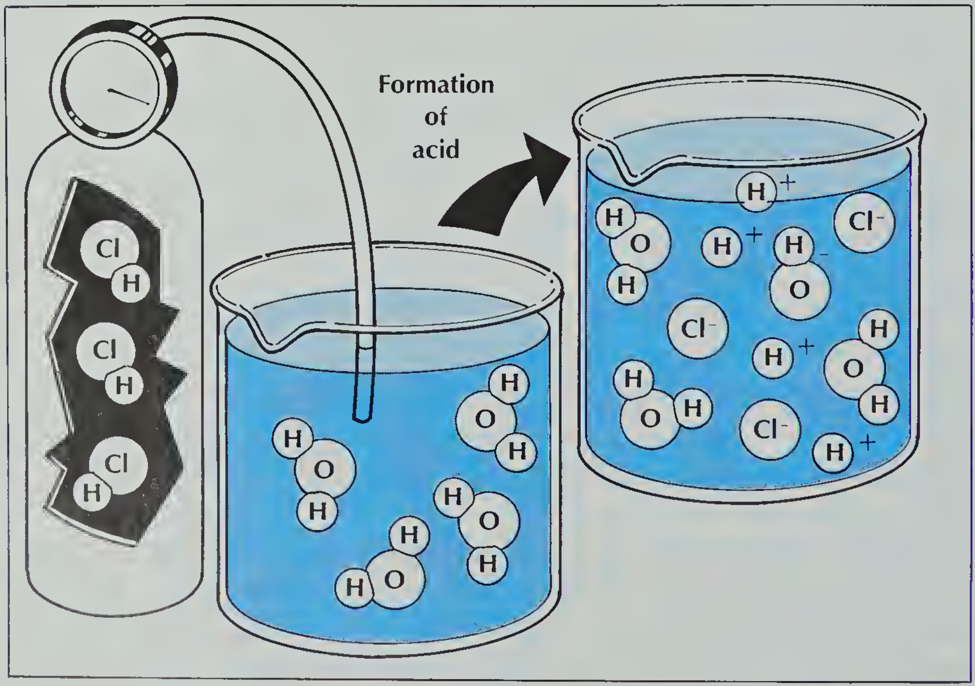


FIGURE 3-12. When an acid is formed, the concentration of hydrogen ions is greater than the concentration of hydroxide ions.

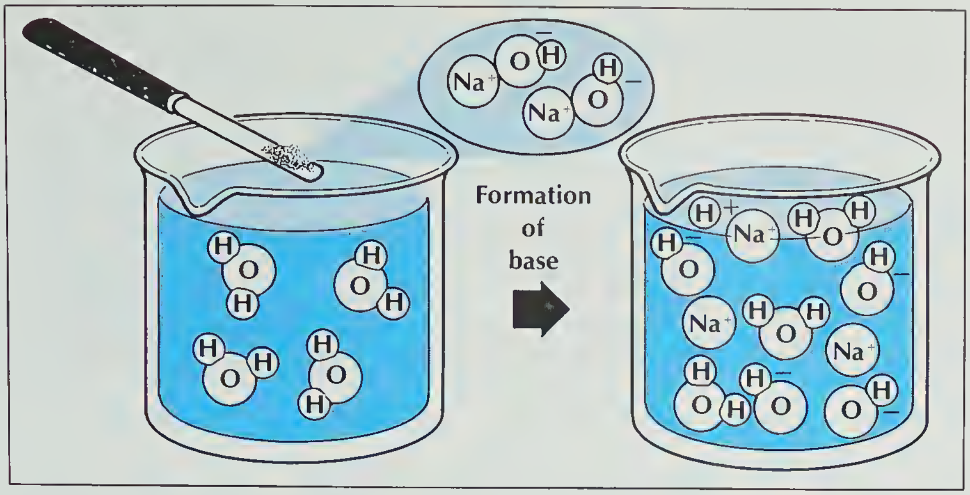


**FIGURE 3-13.** When a base is formed, the concentration of hydroxide ions is greater than the concentration of hydrogen ions.

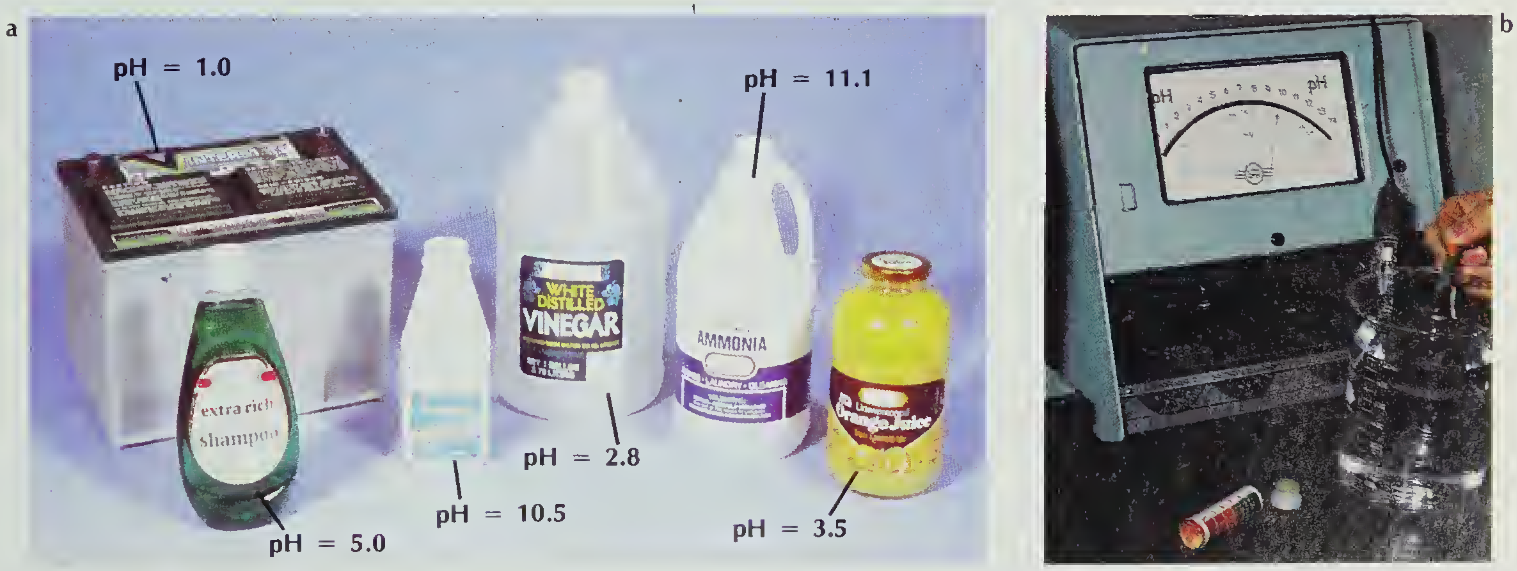
If the number of hydroxide ions in a solution exceeds the number of hydrogen ions, the solution is a **base.** Basic solutions have a sharp, bitter taste, and they feel slippery. In water, sodium hydroxide dissociates into a solution of sodium ions and hydroxide ions. The solution is basic because of an excess of hydroxide ions (Figure 3-13).

In a basic solution, the number of hydroxide ions is greater than the number of hydrogen ions.

Chemists have devised a system for indicating the relative concentration of ions in acids and bases. The system is a scale of numbers, called the **pH scale.** The scale runs from 1 to 14 with 7 representing a neutral solution. Numbers below 7 represent acids. The lower the number, the greater the concentration of hydrogen ions and the more acidic the solution. A solution with a pH of 2 has more hydrogen ions and is more acidic than a solution with a pH of 6. Numbers above 7 represent bases. The higher the number, the greater the concentration of hydroxide ions and the more basic the solution. Therefore, a solution with a pH of 12 has more hydroxide ions and is more basic than a solution with a pH of 9.

Concentrations of ions in acids and bases are represented by a set of numbers called the pH scale.

**FIGURE 3-14.** (a) When the pH of items is determined, it is a number between 1 and 14. (b) The pH can be determined with pH paper or with a pH meter. The pH paper changes color indicating pH. The pH meter indicates pH directly on a scale. Is the solution tested here acidic or basic?



*Lightforce*

*Herm Beck*

**TABLE 3-1. RELATIVE CONCENTRATIONS OF HYDROGEN AND HYDROXIDE IONS IN SOLUTIONS**

| pH | Concentration of Hydrogen Ions | Concentration of Hydroxide Ions | Kind of Solution |
|---|---|---|---|
| 1-7 | Greater than concentration of hydroxide ions | Less than concentration of hydrogen ions | Acid |
| 7 | Equal to concentration of hydroxide ions | Equal to concentration of hydrogen ions | Neutral |
| 7-14 | Less than concentration of hydroxide ions | Greater than concentration of hydrogen ions | Base |

The table above summarizes the meaning of pH scale measurements.

pH influences the habitats and chemical reactions of organisms.

The pH of solutions is important to living systems. The pH of water determines which organisms will live in the water, and the pH of soil determines which organisms will grow in the soil. Also, the pH of solutions influences many of the chemical reactions which take place in organisms. For example, in order for digestion to occur properly, the pH of the stomach must be about 2. However, the pH of the intestine is about 8.

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### REVIEWING YOUR IDEAS

5. What is a molecule? A compound?
6. How are bonded atoms held together?
7. What information does a chemical formula provide?
8. What is a solution? What are the two parts of a solution?
9. What is a neutral solution? Compare an acid to a base. How is the relative strength of an acid or base indicated?

---

# CHANGE IN MATTER

## 3:9 Properties of Matter

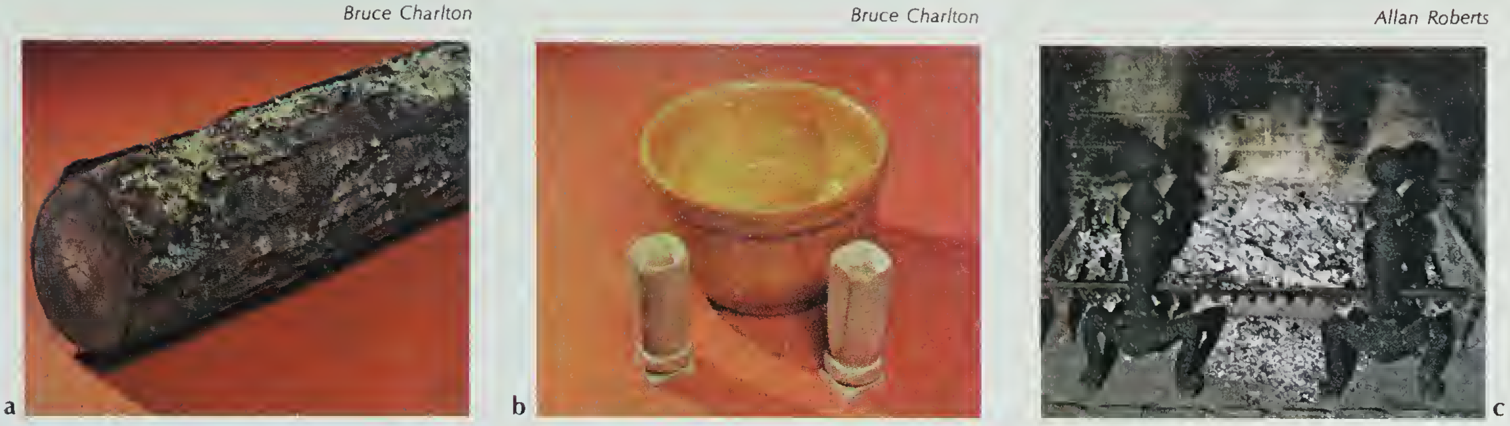
Physical properties describe the features of a substance.

Each material has certain features or properties. A piece of wood has a definite mass, volume, shape, color, hardness, and texture. Such features which describe a piece of matter are called **physical properties.**

In a physical change, the substance itself does not change.

Physical properties and appearance may change. The size, shape, and mass of a piece of wood can be changed by sawing or carving it, but after it is sawed, it is still wood. Any change in the physical properties of a substance which does not change the substance is a **physical change.** Other examples of physical changes include stretching a rubber band and molding clay.

What happens when you burn a piece of wood? Many of its properties are changed. When wood is burned completely, the only visible remains are ashes which do not resemble the wood.



Bruce Charlton

Bruce Charlton

Allan Roberts

**FIGURE 3-15.** (a) The physical properties of a wooden log are changed when (b) the wood is carved (a physical change). (c) When the wood is burned, the chemical properties are changed (a chemical change).

Burning is a **chemical change,** a change rearranging the atoms or molecules of the materials involved. A chemical change may involve the formation of new bonds between two or more substances or the breaking of bonds between atoms. When wood burns, it combines with oxygen in the air, and the carbon, hydrogen, and oxygen of the wood are rearranged to form new substances with new properties. The new substances formed are the invisible gases carbon dioxide and water vapor. Such a change is called a **chemical reaction.**

A chemical change involves the rearranging of atoms or molecules as new substances are formed.

A property of the wood is that it can be burned—wood can combine with oxygen to form new substances. A **chemical property** is a property which depends on the substance's being changed into a new substance or substances. For instance, sodium atoms combine with chlorine atoms to form a new substance, sodium chloride (table salt). The properties of salt are entirely different from the properties of either sodium or chlorine.

Chemical properties describe how a substance reacts with other substances.

## 3:10 Chemical Equations

By using chemical shorthand, you can show chemical reactions. When iron rusts, it reacts chemically with oxygen. The chemical reaction of iron and oxygen to form iron oxide can be expressed in words.

Write a word equation for the formation of table salt.

Iron plus oxygen yields iron oxide.

A + can be used for "plus" and an → can be used for "yields."

$$\text{iron} + \text{oxygen} \longrightarrow \text{iron oxide}$$

This reaction can also be shown using symbols and formulas rather than words to represent the elements and compounds involved in the reaction. A statement describing a chemical reaction with symbols and formulas is a **chemical equation.** All chemical reactions can be written as chemical equations. In the equation for the formation of iron oxide, iron and oxygen are called **reactants,** and iron oxide is the **product** of the reaction.

A chemical equation describes a chemical reaction.

A chemical equation is like an algebraic equation in that both sides must represent the same quantity. *The number of atoms of each element on each side of the arrow must be equal.* The **law of conservation of mass** is followed: *during a chemical reaction, mass is neither created nor destroyed.* Therefore, a chemist would write the equation for the formation of iron oxide as follows:

$$4\text{Fe} + 3\text{O}_2 \longrightarrow 2\text{Fe}_2\text{O}_3$$

The sum of each kind of atom is the same on both sides of a balanced equation.

This statement is a **balanced equation** because the number of atoms of each element is the same on both sides. Four iron atoms must combine with three molecules of oxygen to produce two units of iron oxide.

---

**REVIEWING YOUR IDEAS**

10. What is a physical property? What is a physical change?
11. What occurs during a chemical change? How do physical changes and chemical changes differ?
12. What is a chemical equation? What is a balanced equation? Why must an equation be balanced?
13. How are chemical equations and reactions related?

---

## BIOLOGICAL CHEMISTRY

### 3:11 Carbon Compounds

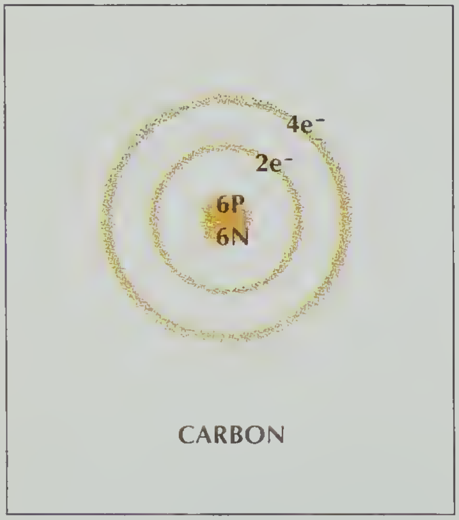
Biologists and chemists have been aware for many years of complex compounds being produced by living things. Because they were found in organisms, these substances were named **organic compounds.** At first scientists thought organic compounds could be produced only by living systems and not in the laboratory. Chemists have since learned to make them, but the name organic compound has remained.

Analysis of organic compounds shows that they all contain the element carbon. They now are also called **carbon compounds.** The study of these compounds is called **organic chemistry.**

Carbon atoms are relatively simple in structure with six electrons. Because carbon has four electrons in its outer level (Figure 3-16), a carbon atom "needs" four more electrons in forming bonds with other atoms (Section 3:3). Carbon atoms obtain these electrons by forming covalent bonds.

A carbon atom can join with other kinds of atoms and with other carbon atoms. The complex molecules found in living systems are composed of long chains of carbon atoms. Inorganic compounds (those not containing carbon) consist of small numbers of atoms.

FIGURE 3-16. An atom of carbon has four electrons in its outer energy level. It forms bonds by sharing electrons with other atoms.



## 3:12 Structural Formulas

Chemical formulas discussed so far are called **simple formulas.** The formula $H_2O$ shows the kinds and number of atoms per molecule of water. However, organic compounds present a problem because they are complex. Because their properties are easier to understand if the arrangements of their atoms in space are known, organic compounds often are shown by **structural formulas.**

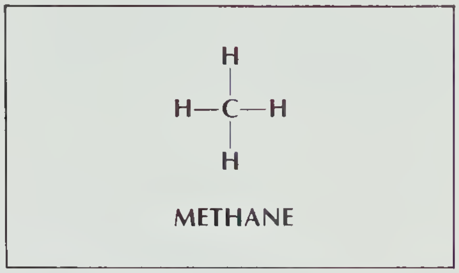


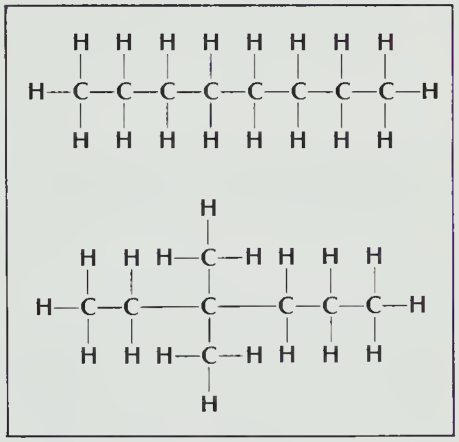
**FIGURE 3-17. A structural formula of methane shows the arrangement of the atoms.**

Methane is a compound composed of one carbon atom and four hydrogen atoms per molecule. Its simple formula is $CH_4$, but its structural formula shows more about the compound (Figure 3-17). The formula shows that each of the four hydrogen atoms is bonded to the central carbon atom. Each line drawn between atoms represents a covalent bond, the sharing of one pair of electrons. One line between two atoms is a single covalent bond (C—C). Two lines between two atoms is a double covalent bond (C═C), the sharing of two pairs of electrons. Three lines would be a triple bond (C≡C) in which three pairs of electrons are shared. Because a hydrogen atom shares only one electron, each hydrogen atom has only one bond.

Structural formulas show the arrangement of atoms in space.

Figure 3-18 shows two possible structural formulas for $C_8H_{18}$. In each formula, each carbon atom has four bonds and each hydrogen atom has one bond as required by electron numbers. Compounds which have the same simple formula but different structures are called **isomers** (ɪ suh murz). The existence of isomers is one reason chemists prefer to use structural formulas to represent organic chemicals. With structural formulas, there is usually no doubt about which isomer is meant.

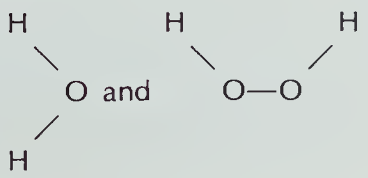
**FIGURE 3-18. Each of these structures has the formula $C_8H_{18}$. Because the arrangement of the atoms differs, the structures are isomers.**

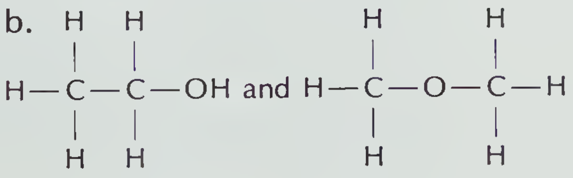


Isomers have different physical and chemical properties. For example, there are two isomers of the sugar lactose, commonly found in milk. Babies can readily digest only one form.

### REVIEWING YOUR IDEAS

14. How is the term "organic compound" defined today? How is this definition better than the original meaning?
15. What information is given by a structural formula that is not given by a simple formula?
16. Which type of formula, structural or simple, gives more information about a compound?
17. What is an isomer? Which of the following are isomers?

a.


b.


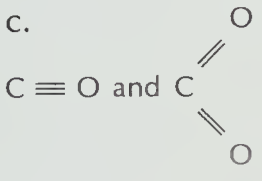
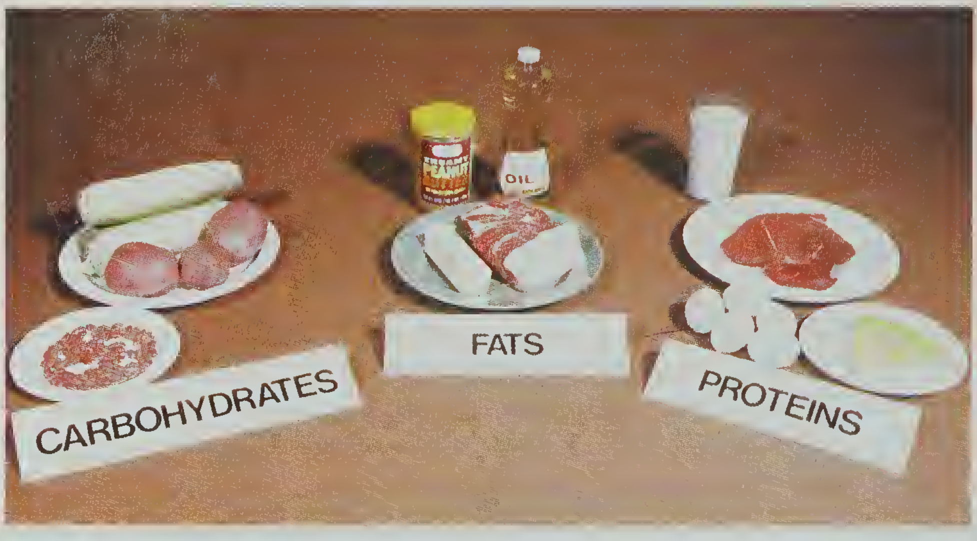
c.


FIGURE 3-19. Certain foods are high in carbohydrates, fats (lipids), and proteins.

Lightforce



## 3:13 Carbohydrates

Carbohydrates are composed of carbon, hydrogen, and oxygen.

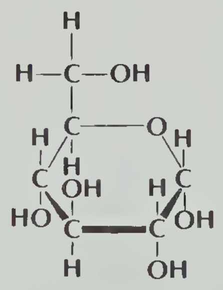
One of the most important groups of organic compounds of living systems is the **carbohydrates.** Carbohydrates are composed of carbon, hydrogen, and oxygen with a ratio of two hydrogen atoms to one oxygen atom. Glucose, the sugar produced by plants, is an important carbohydrate (Figure 3-19). Glucose and most other carbohydrates are energy sources for organisms. What would happen if all plants suddenly stopped producing glucose?

Monosaccharides are the basic building blocks of carbohydrates.

Glucose, $C_6H_{12}O_6$, is an example of the simplest type of carbohydrate, a **monosaccharide** (mahn uh SAK uh ride), or single sugar. Monosaccharides are the building blocks of complex carbohydrates.

Two monosaccharides can join to form a **disaccharide,** or double sugar. Table sugar (sucrose) is a disaccharide formed from joining one molecule each of glucose and fructose (another monosaccharide). Maltose is a disaccharide formed from two molecules of glucose. Both of these disaccharides have the simple formula $C_{12}H_{22}O_{11}$. Lactose, another isomer, is formed from one molecule each of glucose and galactose.

FIGURE 3-20. The structural formula of glucose, a monosaccharide, shows a ring made of one oxygen and five carbon atoms.



Glucose ($C_6H_{12}O_6$)

Larger carbohydrate molecules, **polysaccharides,** are also found in living systems. The most complex of all carbohydrates, the **starches,** are composed of hundreds of monosaccharides linked together. Plants produce more sugar than they use. They "store" excess sugar in the form of starch. A potato, kernels of corn, and beans are mostly starch. This starch will be used as food for the new plants which grow from the potato and seeds. Some polysaccharides, such as **cellulose,** are used by plants for structural purposes. Cellulose is similar to starch. **Glycogen** (GLI kuh jun) is a starchlike carbohydrate in animals. When needed, glycogen is broken down into monosaccharides which are "burned" for energy.

## 3:14 Lipids

**Lipids** are a class of organic compounds which includes fats, waxes, and oils. They are used for energy and often are stored as energy reserves. Usually, solid fats are produced by animals, and liquid oils are produced by plants. Waxes are produced by both plants and animals. Like carbohydrates, lipids are composed of carbon, hydrogen, and oxygen, but the number of carbon and hydrogen atoms per molecule is much greater than the number of oxygen atoms. Thus, most fats are more complex than carbohydrates.

A fat molecule (Figure 3-21) is formed from two less complex molecules: **fatty acids** and **glycerol** (GLIHS uh rawl). There are many different fatty acid molecules, but all of them have a certain part in common, a **carboxyl** (kar BAHK sul) **group** (—COOH). In the structural formula of a fatty acid (Figure 3-21), R represents a long chain of carbon and hydrogen atoms. The exact number, arrangement and bonding of these atoms accounts for the differences among fatty acids.

Notice that there is a double bond between the carbon atom and one oxygen atom. This double bond represents the sharing of two pairs of electrons (Section 3:12). A double bond occurs because each oxygen atom may share two pairs of electrons with the same atom in forming compounds. Also, carbon must share four electron pairs and hydrogen must share one electron pair. Check the general formula again to see whether all these requirements have been met.

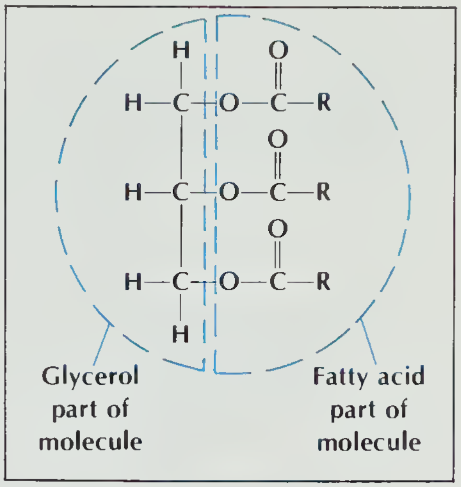


**FIGURE 3-21.** Glycerol, $C_3H_5(OH)_3$, combines with three fatty acids to form a molecule of fat.

Fats are composed of fatty acids and glycerol.

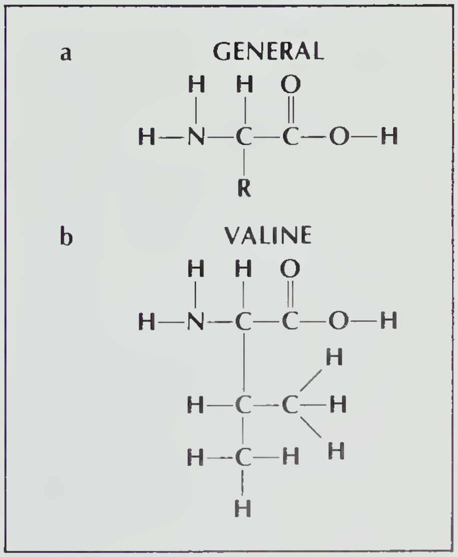
## 3:15 Proteins

**Proteins** are the building blocks of living material. They make up much of the structure of living things. Proteins are important in the growth, maintenance, and repair of living material. Certain proteins are also essential in running the chemical reactions in living organisms (Section 4:3).

Like lipids and carbohydrates, proteins contain carbon, hydrogen, and oxygen; but, they also contain nitrogen. Proteins also can contain other elements such as sulfur. Proteins are much larger and more complex than either lipids or carbohydrates.

Proteins are made of compounds called **amino** (uh MEE noh) **acids.** Most of the twenty amino acids important to living things contain a central carbon atom to which is attached a carboxyl group (–COOH), a hydrogen atom, and an **amino group** (–$NH_2$). Also attached to the carbon atom is the rest of the molecule, the part that makes each amino acid different. It is represented by the letter R.

**FIGURE 3-22.** (a) The general formula for an amino acid shows a central carbon atom to which are attached the amino group, the carboxyl group, and the R group. (b) Find each of these groups in valine.



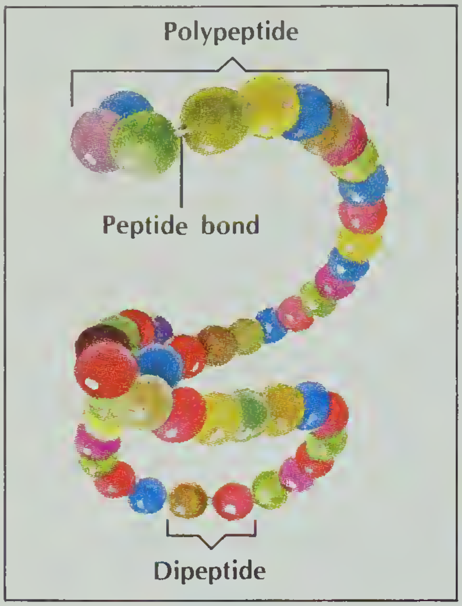


**FIGURE 3-23. A protein is made of amino acids held together by peptide bonds. Proteins differ in the kind, number, sequence, and arrangement of amino acids.**

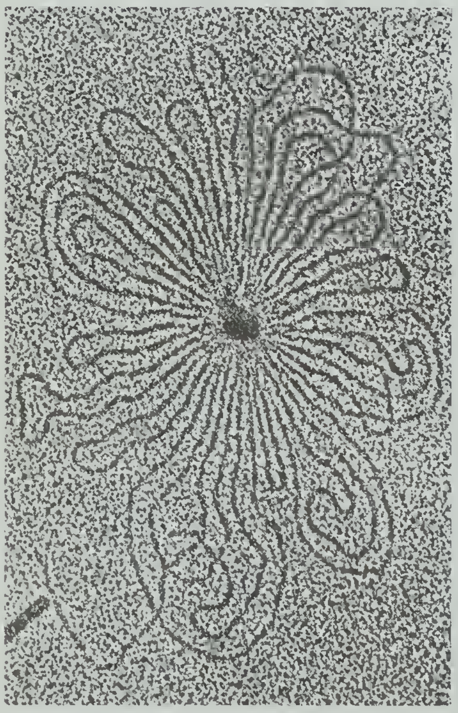
Two amino acids are held together by a **peptide bond.** Two amino acids joined together by a peptide bond form a **dipeptide.** Many amino acids joined together form a **polypeptide.**

Polypeptides combine to form large protein molecules consisting of hundreds or thousands of amino acids. One protein differs from another in its kind, number, sequence, and arrangement of amino acids. Hair and fingernails are proteins that differ because of their amino acids. As the twenty-six letters of the alphabet form many words, the twenty amino acids can form an almost endless number of proteins. It is estimated that there are between 10 000 and 50 000 different kinds of human proteins.

**TABLE 3-2. IMPORTANT BIOLOGICAL MOLECULES**

| Compound | Elements Present | Building Blocks | Use |
|---|---|---|---|
| Carbohydrate | Carbon<br>Hydrogen<br>Oxygen | Monosaccharides | Energy |
| Fat | Carbon<br>Hydrogen<br>Oxygen | Fatty Acids<br>Glycerol | Energy reserve |
| Protein | Carbon<br>Hydrogen<br>Oxygen<br>Nitrogen<br>Sulfur | Amino Acids | Building living material<br>Regulating chemical reactions |

**FIGURE 3-24. A nucleic acid, DNA, from a virus is shown magnified 65 000 times.**



*Science Photo Library International*

## 3:16 Nucleic Acids

**Nucleic** (noo KLAY ihk) **acids** are the most complex of all biological compounds. They are extremely large molecules which may consist of hundreds of thousands of atoms. Two very important nucleic acids are **deoxyribonucleic** (dee AHK sih ri boh noo KLAY ihk) **acid** (DNA) and **ribonucleic** (ri boh noo KLAY ihk) **acid** (RNA) which control heredity. DNA is the material which usually contains the "genetic message." RNA works with DNA in carrying out the instruction of the DNA code. You will study this process in Chapter 9.

## 3:17 Reactions of Organic Compounds

You have seen that organic compounds may combine to form larger molecules. Also, large compounds can be changed to smaller ones. As in any chemical reaction, old bonds must be broken and new bonds formed.

Consider the linking of two amino acids to form a dipeptide. The bonds that are broken involve oxygen and hydrogen atoms.

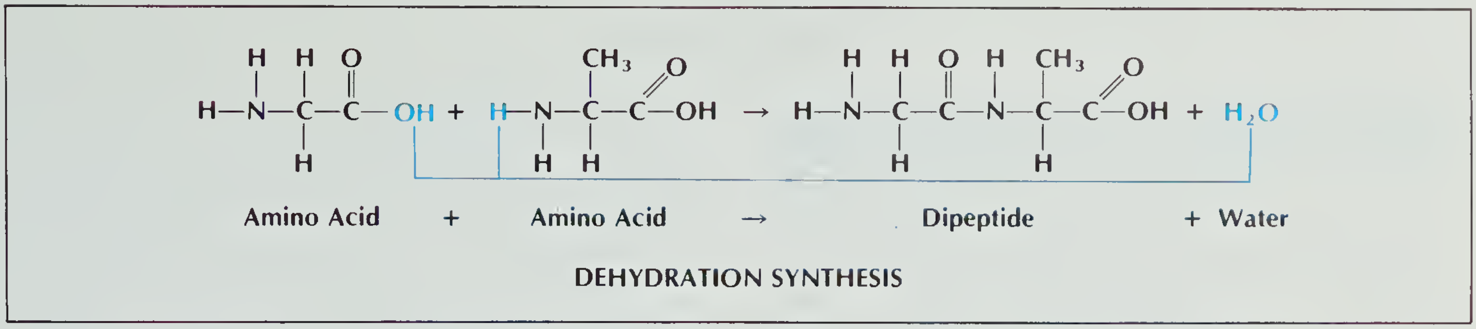


**FIGURE 3-25.** When water is removed (dehydration), a dipeptide is formed from amino acids by dehydration synthesis.

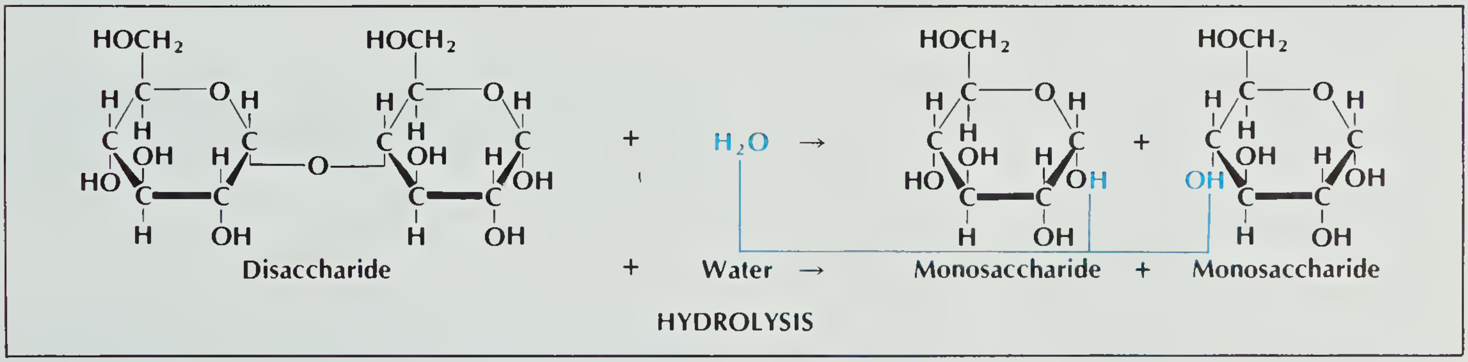
One hydrogen atom is removed from one amino acid. The other amino acid loses an oxygen atom and a hydrogen atom (Figure 3-25). These atoms always come from the same parts of the amino acids. When these atoms are removed, electrons become available for sharing and the two amino acids join together. The two hydrogen atoms and one oxygen atom removed during the reaction join to form a molecule of water. Because the new molecule is made by removing a molecule of water, the process is called **dehydration synthesis.**

Large molecules commonly are made in a cell by dehydration synthesis.

Dehydration synthesis is common in all cells. It occurs in synthesizing fats from fatty acids and glycerol. It also occurs in constructing larger carbohydrate molecules from monosaccharides.

Dehydration synthesis is reversed when large molecules are split into smaller molecules. A bond holding the larger molecule together is broken, and a molecule of water is added to form two smaller molecules. This process is called **hydrolysis** (hi DRAHL uh sus) because water is added (Figure 3-26). Like dehydration synthesis, hydrolysis is a common type of cell reaction.

**FIGURE 3-26.** Water is added in the breaking (hydrolysis) of a disaccharide into monosaccharides.



## REVIEWING YOUR IDEAS

18. How are carbohydrates important to organisms?
19. What are lipids? How are fats used by living systems?
20. How are proteins used by organisms?
21. Name two nucleic acids. What are their functions?
22. Name a cellular process that breaks large molecules into smaller ones. Name a cellular process that builds.

# CHAPTER REVIEW

## SUMMARY

1. Matter is composed of atoms which are made of protons, neutrons, and electrons.
2. Elements are substances composed of one type of atom. Molecules and ionic compounds form when atoms join by covalent or ionic bonds.
3. Ions form when atoms gain or lose electrons.
4. Solutions form when molecules dissolve and ionic compounds dissociate in a solvent.
5. The concentration of hydrogen ions in acids and bases is measured by the pH scale.
6. Matter has both physical and chemical properties and can undergo both physical and chemical changes.
7. Complex carbon-containing compounds are found in living systems.
8. Carbohydrates, lipids, proteins, and nucleic acids are the major groups of carbon compounds important to living systems.
9. Dehydration synthesis and hydrolysis are important reactions of organic compounds.

## LANGUAGE OF BIOLOGY

acid
amino acid
atom
base
carbohydrate
compound
covalent bond
dehydration synthesis
electron cloud
element
fatty acid
formula
glycerol
hydrolysis
ion
ionic bond
isomer
isotope
lipid
matter
molecule
neutron
nucleic acid
pH scale
protein
proton
solution

## CHECKING YOUR IDEAS

*On a separate paper, complete each of the following statements with the missing term(s). Do not write in this book.*

1. In an atom with no overall charge, the number of protons equals the ____.
2. Ionic bonds result from the ____ of electrons.
3. ____ are the main building blocks of living material.
4. To show arrangement of parts, organic compounds are shown by ____ formulas.
5. A(n) ____ is a homogeneous material of a solute in a solvent.
6. The stretching of a spring is an example of a(n) ____ change.
7. A(n) ____ is composed of atoms joined by covalent bonds.
8. A total of ____ atoms is shown by $4H_2O$.
9. ____ and ____ are the main energy sources of living systems.
10. A molecule of fat is changed to fatty acids and glycerol by the process of ____.
11. A dipeptide consists of ____ amino acids.
12. Heredity is controlled by ____ and ____, two kinds of large organic molecules.
13. During a(n) ____ change, new substances with new properties are formed.
14. The part of an atom involved in bond formation is the ____.
15. Isotopes of an element have different numbers of ____.

## EVALUATING YOUR IDEAS

1. Why is knowledge of chemistry and physics important to a biologist?
2. List the four elements most common in living things. What are their symbols?
3. What happens to the outer energy level when an atom joins with another atom?
4. Why must a molecule of water be composed of two hydrogen atoms and one oxygen atom?
5. What is the difference between a chlorine atom and a chloride ion?
6. How are ionic compounds different from molecular compounds?

## CHAPTER REVIEW

7. What is meant by the expression $3H_2O$? How many atoms are there in $3H_2O$?
8. Describe the difference between a solution of sugar in water and a solution of salt in water.
9. Why is a solution of hydrogen chloride in water an acid? Why is a solution of sodium hydroxide in water a base?
10. A chemist tests two solutions. One has a pH of 6. The other has a pH of 2. Which is more acidic? Explain.
11. What properties of carbon make it suitable as a part of complex molecules?
12. What is a double bond? What is a triple bond? Why can't hydrogen form double or triple bonds?
13. What group of atoms is common to both fatty acids and amino acids?
14. What element found in proteins is not found in either lipids or carbohydrates?
15. How does one protein differ from another?
16. With what important biological function are the nucleic acids associated?
17. Classify each reaction below as either a hydrolysis or dehydration synthesis.
    - (a) conversion of starch to glucose
    - (b) synthesis of protein from amino acids
    - (c) production of a disaccharide from monosaccharides
    - (d) conversion of a protein to dipeptides
    - (e) conversion of fats to fatty acids and glycerol

## APPLYING YOUR IDEAS

1. A certain atom has 8 protons and 10 neutrons. How many electrons does it have? Draw a diagram of this atom.
2. One ion has a charge of 3+. Another ion has a charge of 1−. How would the two ions combine to form a neutral compound?
3. Helium, argon, and neon are atoms whose outer energy levels are filled. They are known as noble (inactive) gases. Why are they inactive?
4. Bromthymol blue is a substance which is yellow-green in the presence of an acid and blue in the presence of a base. When $CO_2$ is dissolved in water, an acid is formed. Suppose $CO_2$ is dissolved in water to which bromthymol blue has been added. What color is the water? What would happen to the color of the water if an aquatic green plant were placed in it? Why?
5. Which of the following changes are physical and which are chemical?
    - (a) tearing a sheet of paper
    - (b) melting of ice
    - (c) joining of two monosaccharides
6. Butane, $C_4H_{10}$, is an organic compound containing single covalent bonds. Draw structural formulas of 2 isomers of $C_4H_{10}$.
7. Ecologists are concerned about the effects of acid rain. What pH range could acid rain have? How might acid rain affect the environment?

## EXTENDING YOUR IDEAS

1. List ten common chemical changes.
2. How would you separate a mixture of sand and iron filings? Of sand and salt?
3. Using reference materials, determine how the pH of the blood is kept constant. What happens if the blood pH varies too much?
4. Prepare a report on cholesterol and its possible effects on humans.
5. Prepare a demonstration showing how various indicators are used to tell pH.

## SUGGESTED READINGS

Baker, J.J.W. and Allen, G.E., *Matter, Energy, and Life: An Introduction for Biology Students.* Reading, MA, Addison-Wesley, 1975.

Rosenfeld, Albert, "The Great Protein Hunt." *Science 81,* January/February, 1981.

Wallace Kirkland for Tom Stack and Associates

*Living things need energy to maintain life processes. Energy must not only be present but it must be in a form usable within the cells of an organism. Here, chemicals within the tissues of the firefly release energy causing the firefly to glow. What types of energy changes occur in this process and other processes within living things? In what forms can energy exist? How is one form changed to another?*

Chapter

4

# ENERGY FOR LIFE

**GOAL:** You will gain an understanding of the need for and uses of energy and the process of cellular respiration.

Living systems require a supply of energy for growth and development, maintenance and repair, reproduction, and overall organization. Without a constant input of energy, no single organism or community could long survive. Energy is necessary for life.

What is energy? The best way to define energy is to describe what it does. The movement of a car, the running of an air conditioner, and the changing of ice to water all require energy. Each of these examples involves motion and can be considered to be work. **Energy** is the ability to do work or cause motion.

Energy is the ability to do work or cause motion.

In living things, energy is used for biological work or motion. Without energy muscles would not contract, certain particles would not move into or out of cells, and new living tissue would not be built. Can you think of other ways in which organisms use energy?

Energy is used for biological work.

## ENERGY AND REACTIONS

### 4:1 Changes in Forms of Energy

Consider a rock at the top of a hill. If the rock is pushed over the side, it will roll down the hill. As it is rolling, the rock could do work or cause motion such as knocking down trees on the hill. At the bottom of the hill, the rock stops rolling and can no longer do work.

Now think about burning wood. As the wood burns, heat and light (radiant energy) are released. The energy could be used for work. For example, the heat could be used to cook food or warm a room. Eventually, the wood will all be burned and no more work can be done.

Thomas Zimmerman/Alpha

Thomas Zimmerman/Alpha

**FIGURE 4-1. (a) A bobsled team at the top of the run has high potential energy and low kinetic energy. (b) While on the run, the potential energy is converted to kinetic energy.**

Potential energy can be converted to kinetic energy.

Both the rock at the top of the hill and the wood have high potential energy. **Potential energy** is energy of position or stored energy. As the rock rolls down the hill or as the wood is burned, the potential energy is converted to kinetic energy. **Kinetic energy** is energy of motion. The rock at the bottom of the hill and the products formed from burning the wood have low potential energy. The difference between the high and low potential energies equals the energy released.

Energy, either potential or kinetic, can be in many forms and can change from one form to another. The potential energy in the wood molecules is called **chemical energy.** That energy is "stored" in the bonds of the molecules in wood cells. (Where did that energy come from originally?) When wood is burned, old bonds are broken and new bonds are formed. The potential chemical energy is changed to heat and light (radiant energy).

Energy is conserved as it changes form.

Any time energy changes form, it is conserved so that the total amount of energy in a system is constant. For example, in the burning of wood, some energy is released and can be used for work. Some of the original energy exists in the bonds of the new compounds formed, carbon dioxide and water. The total amount of this energy is equal to the amount of energy in the wood and the oxygen with which it reacted. The **law of conservation of energy** is: *energy is neither created nor destroyed, but it can be changed from one form to another.*

In cells, potential chemical energy is converted to kinetic energy used for work.

Changes of energy are important to living things. *Cells depend upon potential chemical energy in the bonds of energy-rich molecules. When the bonds are broken, the potential energy is converted to kinetic energy which can be used by cells for biological work.*

## 4:2 Activation Energy

You know that sugar by itself in a dish will not burn. Even though oxygen molecules in the air are colliding with the sugar molecules, no reaction occurs. But if the sugar is heated, it will burn (combine with oxygen). A chemical reaction will occur. The energy boost needed to get the reaction started is called **activation energy.** In this case, the activation energy was the heat you added. Just as a push (activation energy) is needed to start the rock rolling, heat is needed to get the sugar burning.

Once the reaction starts, the activation energy can be removed and the reaction will continue. Energy in the form of heat and light will be released and carbon dioxide and water will be formed. The energy released during the burning of sugar was present *in* the sugar molecules. Some of this potential energy was transformed into radiant energy (heat and light) as the sugar burned. No energy was lost in the process; it only changed forms (Section 4:1).

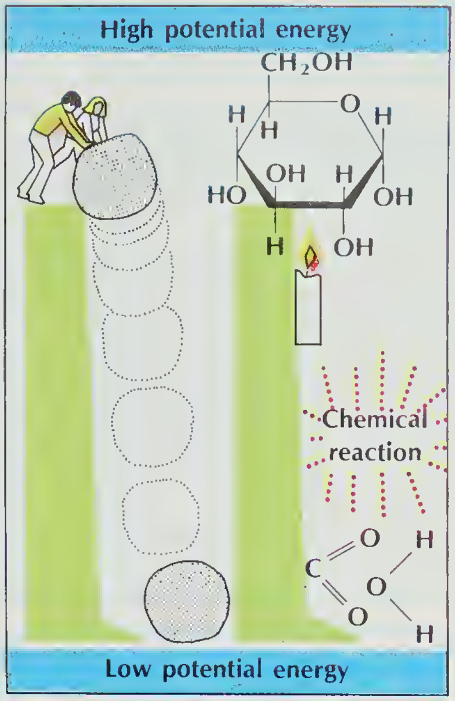


**FIGURE 4-2.** Activation energy is required to start a rock rolling down a hill and to start many chemical reactions. In both cases, potential energy is converted to kinetic energy as the processes occur.

### REVIEWING YOUR IDEAS

1. Distinguish between potential and kinetic energy.
2. How do cells obtain their usable energy?
3. What is activation energy? What form of energy is often used to speed up chemical reactions in a chemistry lab?

# ENERGY FOR CELLULAR WORK

## 4:3 Enzymes

In some ways, the chemical reactions of living and nonliving things are alike. For example, sugar in a test tube burns by using up oxygen, and a mouse needs oxygen to burn its food in order to stay alive. But there are differences. The test-tube reaction gives off heat and light while the mouse gives off a little heat but no light. Burning in the test tube is "explosive"; the energy is released quickly. In the mouse, even though energy is released quickly, the "burning" of food is controlled.

In a cell, sugar is "burned" so that energy is released slowly.

Heat energy is the activation energy for the sugar in the test tube. But heat cannot be the activation energy for chemical reactions in organisms. The amount of heat needed to start most cellular reactions would be so great it would kill the cell. Even if heat could be used, it would cause most reactions to occur at the same time. For a cell to function smoothly, specific reactions must occur at definite times.

Heat is not a suitable source of activation energy for organisms.

If heat is not the source of activation energy in cells, how do cellular reactions get started? Cells contain special chemicals called enzymes (EN zimes). **Enzymes** are chemicals which *lower* the amount of activation energy required and allow reactions to occur at cellular temperatures. Thus, no additional heat is required.

Enzymes lower the activation energy necessary to start biological reactions.

## 4:4 Properties of Enzymes

Since the discovery of the first enzyme, many more have been found. All of these enzymes have certain properties. Each enzyme is specific in that it boosts only one or one type of a cell's many reactions. Also, enzymes themselves are not changed or used up during a reaction.

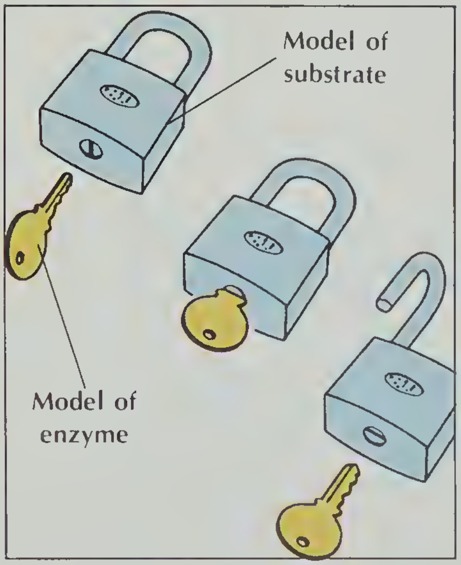
Enzymes are proteins. They are specific and reusable.

Enzymes are proteins, complex molecules made up of amino acids. Because the number of possible arrangements of amino acids is large (Section 3:15), it is not surprising that there are many different enzymes. Each enzyme has a unique three-dimensional shape. The substance upon which a certain enzyme acts is called a **substrate.**

An enzyme often is named by adding the suffix -ase to part of the name of the substrate. Thus, the enzyme which converts maltose to simpler sugars is called maltase. The enzymes which break down proteins are called **proteases** (PROHT ee ays uz). Some enzymes are named on the basis of their function. For example, an enzyme that removes hydrogen is called a dehydrogenase (dee hi DRAHJ uh nays). An enzyme that transfers an amino group is called a transaminase (tranz AM uh nays). Some names of enzymes, such as pepsin, do not end in *-ase*. These enzymes were named before the -ase system of naming was used, although some have been renamed since by the -ase system.

What is the name of the enzyme which breaks down sucrose?

**FIGURE 4-3. According to the lock and key hypothesis, an enzyme fits a specific substrate just as a key fits a specific lock.**



## 4:5 Lock and Key Hypothesis

How does an enzyme lower the activation energy needed to start a reaction? The properties of enzymes have been studied in detail. The **lock and key hypothesis** is one explanation of enzyme function. It explains some enzyme properties.

Every lock has a specific key which will open it. The shape of the key enables it to open a lock. The key is cut so that it matches the tumblers of the lock. Only if the two surfaces fit together will the lock open.

Each substrate can be acted upon only by a specific enzyme. Thus, the surface shapes of the enzyme and substrate must match each other and fit together. Biologists assumed that the enzyme has a special shape which would fit a part of the substrate.

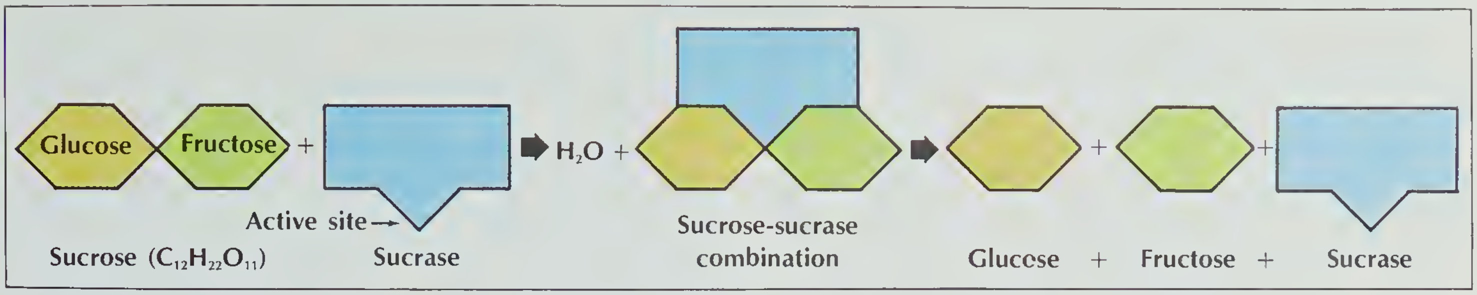

Glucose
Fructose
+
Active site
Sucrose ($C_{12}H_{22}O_{11}$)
Sucrase
$H_2O$ +
Sucrose-sucrase combination
Glucose + Fructose + Sucrase

**FIGURE 4-4. The enzyme sucrase is involved in the breakdown of sucrose. The active site of the enzyme fits the shape of the substrate (sucrose).**

The parts would fit just as a key fits a lock or as two pieces of a jigsaw puzzle fit together. The part of the enzyme molecule which fits the substrate is called the **active site.** This idea explains the fact that each enzyme is specific for its substrate.

Sometimes, other substances alter the shapes of active sites (Section 4:6). In some cases the fit between enzyme and substrate is not exact, but when they join, the shape of the enzyme changes to make a better fit.

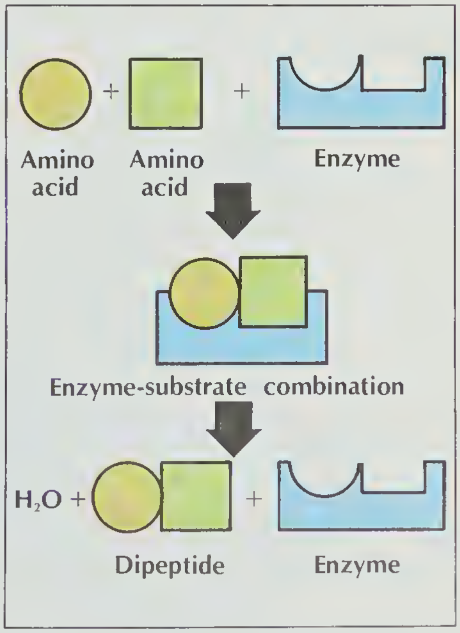
The active site is the "key" which fits the substrate "lock."

Now consider a common biological reaction. Sucrose (table sugar), a disaccharide, breaks down into two monosaccharides, glucose and fructose (Section 3:13). This reaction is a hydrolysis reaction (Section 3:17). It occurs in your intestine as you digest a meal. Although sucrose and water molecules collide, the force of such collisions is not great enough to cause the hydrolysis reaction to occur. The bond holding the two monosaccharides together is too strong.

Now suppose a molecule of sucrose collides with a molecule of the enzyme sucrase (Figure 4-4). According to the lock and key hypothesis, the active site of the sucrase molecule fits a certain part of the sucrose molecule. Thus, if the two molecules collide, they can join. While the sucrase and sucrose are joined, the bond holding the two monosaccharides together is somehow weakened and then broken. A molecule of water is added to complete the reaction. *When an enzyme and substrate are joined, the activation energy requirement is lowered. The reaction, therefore, occurs at cellular temperatures.* After the bonds between glucose and fructose are broken, the enzyme separates from the substrate. The enzyme is not used up or changed during the reaction and can be used over again.

Enzymes also can work in reactions that combine smaller molecules to form a larger molecule. Proteins are formed from amino acids (Section 3:15). To join two amino acids, an enzyme with two active sites is needed—one site fits each amino acid. As the two amino acids lie side by side on the surface of the enzyme, they are in a position which increases the chances for bonds to form between them. Again, while the enzyme and substrates are joined, the activation energy required is lowered. A molecule of water is removed in this dehydration synthesis (Section 3:17). A dipeptide is formed as the two amino acids join (Figure 4-5).

**FIGURE 4-5. In the formation of a dipeptide, an enzyme with two active sites is involved.**



The lock and key hypothesis is supported by experimentation.

Experimental evidence supports the lock and key hypothesis. If the active site of an enzyme is destroyed, the enzyme cannot direct its normal activities. However, if the active site remains and another region is destroyed, the enzyme can sometimes perform properly. Also, a substance with a shape similar to the normal substrate can compete with the substrate. It combines with some of the available enzyme molecules so that the enzyme cannot do its job.

The shape of the active site may be altered when other molecules combine with the enzyme.

Using computers, scientists are identifying the active sites of some enzymes. They have learned where enzymes combine with their substrates. The shape of the active sites of some enzymes may be altered by molecules which either produce the proper active site or distort it. Perhaps these molecules control when an enzyme operates.

## 4:6 Coenzymes

Some coenzymes change the shape of an enzyme's active site.

Some enzymes, during a reaction, join temporarily with other molecules, **coenzymes** (koh EN zimes). In many cases, a coenzyme alters the shape of the enzyme's active site. The enzyme then fits its substrate better and the reaction occurs.

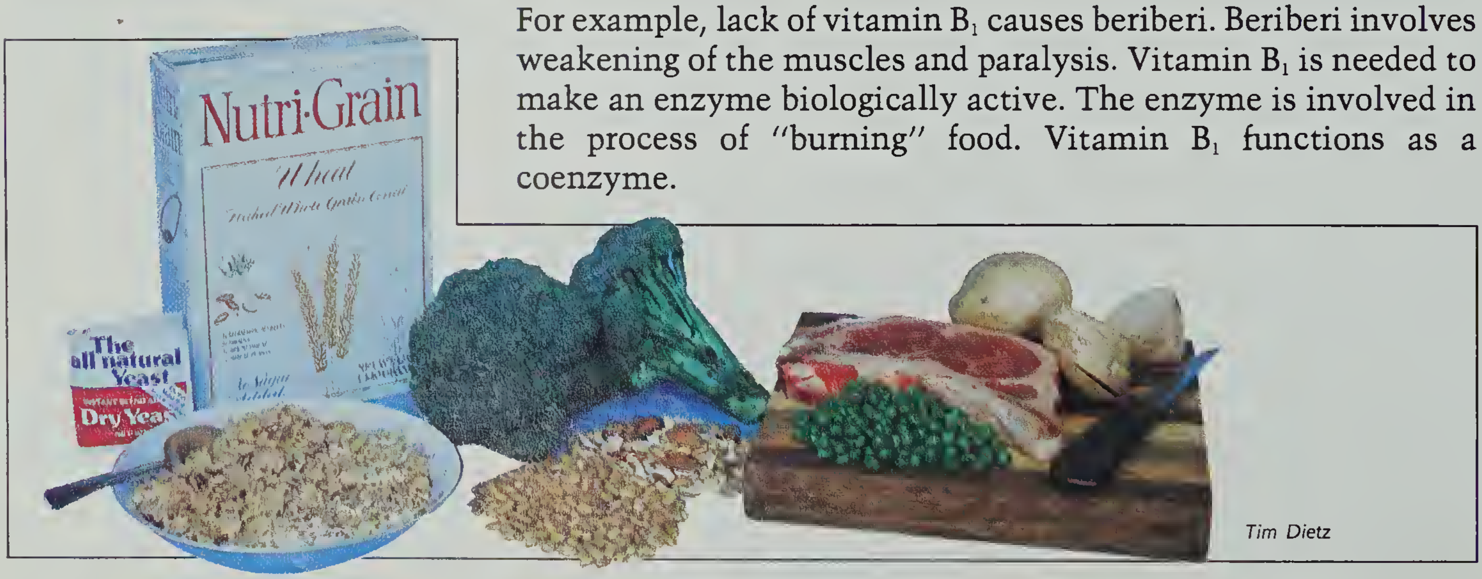
Coenzymes often act as transfer agents.

Coenzymes are usually organic molecules, smaller than enzymes. Like enzymes, they are not consumed during a reaction and can be reused. Coenzymes often serve as transfer agents of atoms, parts of atoms, or groups of atoms during a reaction. For example, an enzyme might remove a hydrogen atom from a molecule. The coenzyme would pick up the atom and donate it to some other substance. The reaction could not occur without the coenzyme to accept the hydrogen.

A well-balanced diet should provide all vitamins required as coenzymes or for the synthesis of necessary coenzymes.

Some essential coenzymes are made from vitamins or vitamin fragments. If an organism's diet does not include enough of a needed vitamin, the coenzyme cannot be made. Certain cellular reactions cannot occur and symptoms of a disease occur. For example, lack of vitamin $B_1$ causes beriberi. Beriberi involves weakening of the muscles and paralysis. Vitamin $B_1$ is needed to make an enzyme biologically active. The enzyme is involved in the process of "burning" food. Vitamin $B_1$ functions as a coenzyme.

**FIGURE 4-6. These foods are high in vitamin $B_1$. A disease called beriberi can result if the diet does not include enough vitamin $B_1$.**



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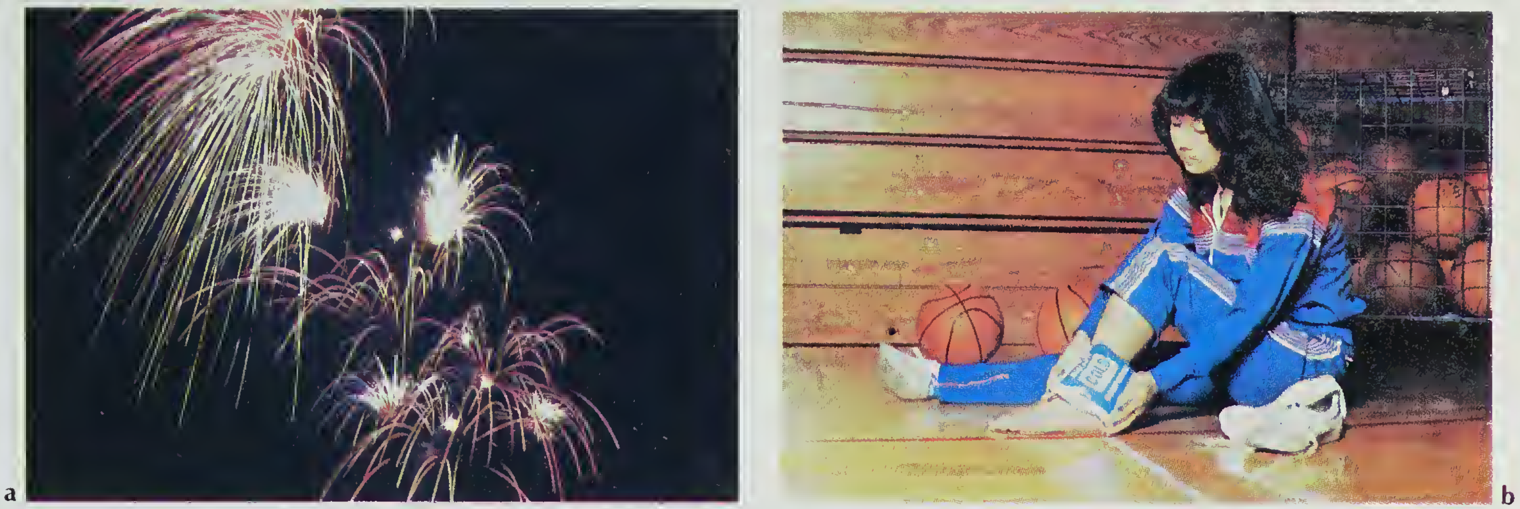
Roger K. Burnard

Tim Courlas

**FIGURE 4-7.** (a) The explosion of fireworks is an exergonic reaction. Heat and light are given off. (b) A cold compress has chemicals undergoing an endergonic reaction. Heat is being absorbed.

## 4:7 ATP

Reactions both inside and outside of living things require activation energy to get started. Once started, some reactions release energy. A reaction that gives off energy is called **exergonic** (ek sur GAHN ihk). Burning wood (wood combining with oxygen) is an exergonic reaction. Activation energy (heat from a match) is required to start the wood burning. Then the wood continues to burn, giving off heat and light.

An exergonic reaction liberates energy.

Some reactions once started use energy. Reactions that use energy are called **endergonic** (en dur GAHN ihk). Compresses sometimes used on sprained ankles contain chemicals that when mixed react with each other. The reaction uses up energy. As the chemicals react and the energy is used, the compress gets colder. Heat energy is absorbed.

An endergonic reaction requires energy.

Many cellular reactions are endergonic. They require an enzyme to lower the activation energy needed. But, they require more than this "spark" of activation energy. They need an additional energy source. The source of energy for most endergonic reactions in a cell is a special kind of molecule. The molecule is called **adenosine triphosphate** (uh DEN uh seen·tri FAHS fayt). This source of chemical energy is commonly called **ATP.** An example of an endergonic reaction using energy from ATP is the synthesis of starch from glucose.

ATP provides energy for most endergonic reactions in cells.

ATP is a complex molecule which can be simplified as A—Ⓟ∿Ⓟ∿Ⓟ. The A stands for the adenosine part of the molecule, and the Ⓟ 's represent groups of atoms called phosphate groups. The wavy lines represent special bonds called **high-energy bonds** between phosphate groups. When these bonds are broken (and new bonds are formed), a large amount of chemical energy is released. The high-energy phosphate bonds liberate about twice as much energy as normal phosphate bonds. *This chemical energy is used in endergonic reactions.*

ATP contains high-energy bonds which, when broken, release chemical energy for endergonic reactions.

ATP is used by cells along with enzymes for endergonic reactions. The energy in ATP is released after an enzyme breaks the bond holding the third phosphate group. Then the molecule contains only two phosphates and is called **adenosine diphosphate** (di FAHS fayt) or **ADP.** A high energy phosphate group, represented as ∼Ⓟ, is also a product. When the high-energy phosphate forms a bond with another substance, chemical energy is released and work is done. As the work is done, the high-energy phosphate is said to change to low-energy phosphate, —Ⓟ (Figure 4-9).

ATP is used in many cellular jobs. For example, energy released from high-energy phosphate is necessary for contracting muscle fibers, lighting a firefly, or conducting nerve impulses. It also drives the many unseen chemical reactions necessary for other cellular activities.

Energy is needed to change ADP and low-energy phosphate to ATP.

Because cells do not have an endless supply of ATP molecules, there must be a way of making more ATP. When a molecule of ATP is used, a molecule of ADP and a low-energy phosphate group are produced and energy is released. ADP and low-energy phosphate can be rejoined to produce ATP. Energy is used in the production of ATP. This energy changes the low-energy phosphate to high-energy phosphate of ATP.

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**REVIEWING YOUR IDEAS**

4. List three characteristics of enzymes.
5. How are enzymes named?
6. Of what are coenzymes made? How do they function?
7. Why is ATP necessary for many cellular reactions? What property of ATP makes it suitable for its function?

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## PRODUCTION OF ATP

Sugar can be "burned" to supply energy for living systems (Chapter 1). The sugar which organisms most commonly use as an energy source is glucose, $C_6H_{12}O_6$. It is the source of energy for making ATP. Why is glucose such a good energy source?

### 4:8 Respiration With Oxygen

Aerobic respiration requires oxygen.

The process in which a cell releases the energy of glucose is called **cellular respiration.** During this process, the energy is transferred to the ATP. Respiration in most cells makes use of oxygen and is called **aerobic** (er ROH bihk) **respiration.** ("Aerobic" means requiring oxygen.)

Thomas Zimmerman/fpg

Thomas Zimmerman/fpg

**FIGURE 4-8.** Oxygen taken in by the body is used in cellular respiration. During exercise, more oxygen is taken in.

The process of aerobic respiration involves many separate chemical reactions which occur in a definite sequence. Each reaction requires an enzyme. Energy is released during certain of these reactions. The following equation summarizes the many reactions of aerobic respiration of glucose:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow[\text{2 ATP}]{\text{enzymes}} 6CO_2 + 6H_2O + \overset{\text{energy for}}{38\text{ATP}}$$

In the series of steps glucose is converted to carbon dioxide and water. *Energy of glucose is released and is used in the formation of ATP from ADP and low-energy phosphate.* Thus, ATP contains energy originally in glucose.

During aerobic respiration, some of the energy in the bonds of glucose is transferred to the bonds of ATP.

Note that some ATP molecules are "invested" in the process. This "investment" is needed because certain early steps require energy. Enough energy, however, is released during later steps to make a large net yield of ATP molecules. The process as a whole is exergonic.

Why must the energy in glucose be transferred to ATP? ATP molecules are the major *usable* energy source in a cell. The step-by-step process of cellular respiration slowly releases the potential energy of glucose and transfers it to ATP. How does this energy release differ from that of the burning of glucose in a test tube?

ATP is the major usable energy source in a cell.

**FIGURE 4-9.** When ATP is converted to ADP and Ⓟ, energy is released which is used in cells for different purposes.

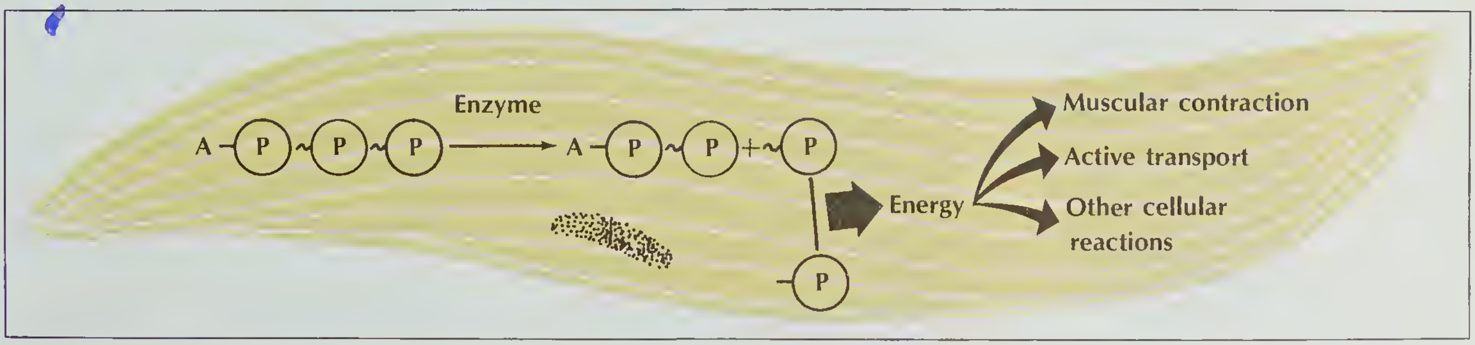


**FIGURE 4-10.** In cellular respiration, the energy of glucose converts ADP and Ⓟ to ATP. The ATP is broken down later releasing energy that is used in cells.

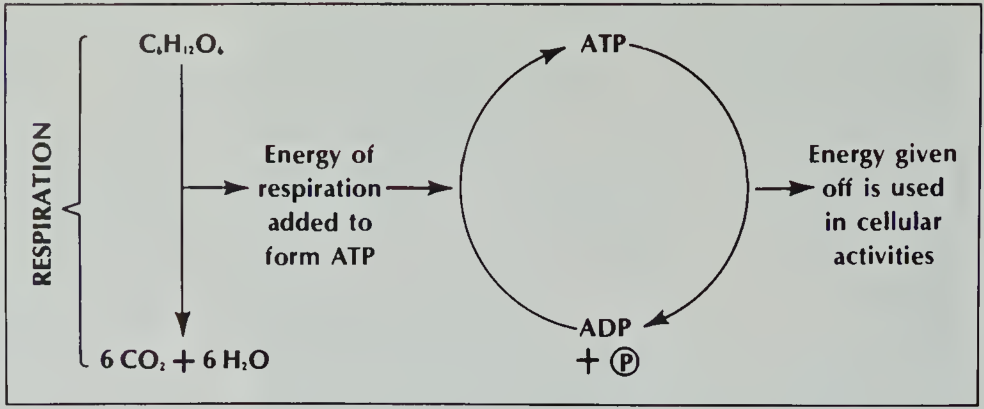

RESPIRATION
$C_6H_{12}O_6$
Energy of respiration added to form ATP
$6\,CO_2 + 6\,H_2O$
ATP
ADP
+ Ⓟ
Energy given off is used in cellular activities

Figure 4-10 summarizes the interrelationships among cellular respiration, ATP, ADP, and the work of the cell. This series of chemical events is called the ATP-ADP cycle. The cycle shows that during aerobic respiration, energy of glucose is released. This energy is used to join ADP and low-energy phosphate to form ATP which can then be used as an energy source for cellular work.

Anaerobic respiration occurs in the absence of oxygen.

## 4:9 Respiration Without Oxygen

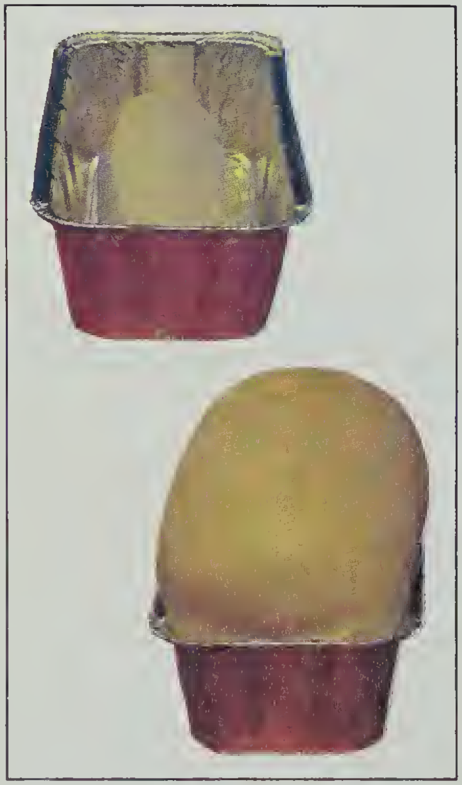
Most cells undergo aerobic respiration, but may change to **anaerobic** (an uh ROH bihk) **respiration** if deprived of oxygen. ("Anaerobic" means not requiring oxygen.) In some cells, anaerobic respiration may occur even if oxygen is present, but some microbes cannot even live in the presence of oxygen. Thus, they rely only on anaerobic respiration for energy.

Most plant cells and microbes commonly undergo a type of anaerobic respiration called alcoholic **fermentation.** Glucose is broken down as shown in the following equation:

$$C_6H_{12}O_6 \xrightarrow[\text{2ATP}]{\text{enzymes}} \underset{\text{(ethyl alcohol)}}{2C_2H_5OH} + 2CO_2 + \overset{\text{energy for}}{4ATP}$$

**FIGURE 4-11.** (a) Anaerobic respiration of yeast produces carbon dioxide which makes bread rise. (b) Anaerobic respiration of certain bacteria causes fermentation of cucumbers in the production of pickles.

a



*Bruce Charlton*

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*Heinz USA* *Heinz USA*

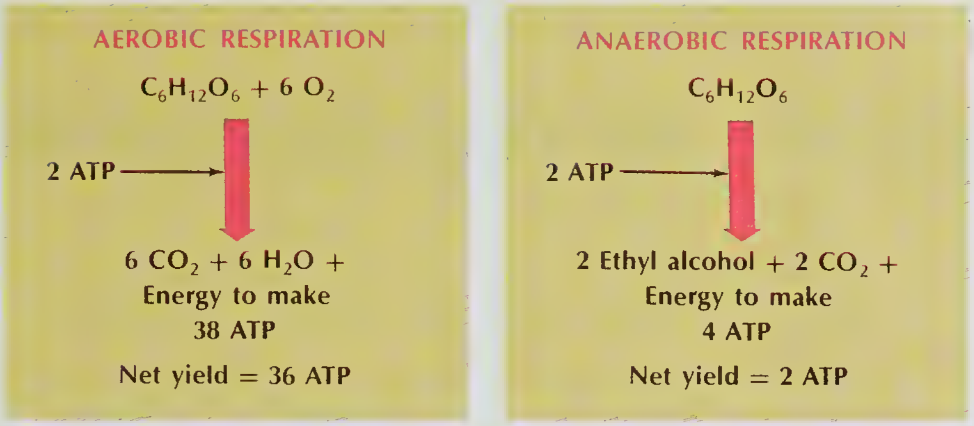

**FIGURE 4-12. Aerobic respiration and anaerobic respiration both produce ATP. What are the main differences in these two processes?**

Notice that no free oxygen is involved in the process. As in aerobic respiration, enzymes and a small amount of ATP energy are required. Energy is released for the formation of more ATP. However, in anaerobic respiration, glucose is not broken all the way down to $CO_2$ and water. Therefore, only a small amount of ATP is netted. The product, ethyl alcohol, has more chemical potential energy than the products of aerobic respiration. Thus, less energy was "released" in the form of ATP.

Anaerobic respiration produces much less energy than aerobic respiration.

Yeasts are useful in industry because of their fermentation products—alcohol and carbon dioxide. Alcohol is used in some beverages. The carbon dioxide formed when yeast cells break down the carbohydrates in dough causes dough to rise. Thus, yeasts are used in the baking industry as well.

Fermentation is useful in the baking and brewing industries.

Many animals and some microbes carry on anaerobic respiration at certain times. For example, during times of heavy physical activity, oxygen may not be supplied fast enough to muscle cells for aerobic respiration to take place. When oxygen is low, the muscle cells "switch" to anaerobic respiration. At these times, glycogen (Section 3:13), which is stored in muscles, is converted to glucose. Glucose is then broken down without oxygen to produce lactic acid. Energy is released and used to form ATP molecules. Thus, energy is supplied for muscle contraction even in the absence of oxygen.

Muscle cells undergo anaerobic respiration when oxygen is unavailable.

Why would oxygen not be supplied quickly enough during heavy exercise?

$$C_6H_{12}O_6 \xrightarrow[\text{2ATP}]{\text{enzymes}} \underset{\text{(lactic acid)}}{2CH_3CHOHCOOH} + \overset{\text{energy for}}{\text{4ATP}}$$

Figure 4-12 compares the events of aerobic and anaerobic respiration. Examine the figure closely.

## REVIEWING YOUR IDEAS

8. What is cellular respiration? Why is it necessary? How is it related to breathing?
9. Contrast aerobic and anaerobic respiration.

# CHAPTER REVIEW

## SUMMARY

1. Energy is the ability to do work or cause motion. In living things, energy is used for biological work or motion.
2. Organisms obtain usable energy by breaking down high-energy molecules. Chemical potential energy is converted to kinetic energy.
3. All chemical reactions require activation energy to get started. Enzymes lower the required activation energy in cells.
4. Each cellular reaction requires a certain enzyme. The lock and key hypothesis is one explanation of enzyme function and also explains some enzyme properties.
5. Coenzymes work along with many enzymes. A coenzyme may combine with an enzyme to alter the enzyme's active site. Coenzymes also act as transfer agents.
6. When the high-energy bonds of ATP are broken, energy is released for biological work. ATP is used in all cellular jobs.
7. Each time a molecule of ATP is used, the cell is left with a molecule of ADP and low-energy phosphate. ADP and low-energy phosphate can rejoin in a cell when energy is added.
8. Most cells break the bonds of glucose by the process of aerobic respiration. Much ATP results from the aerobic respiration of one glucose molecule. The process of aerobic respiration involves many separate chemical reactions which occur in a definite sequence.
9. Transfer of energy from glucose to ATP is necessary because ATP is the major usable energy source in cells.
10. Less ATP is formed from the anaerobic breakdown of one molecule of glucose than from the aerobic breakdown. Fermentation is a type of anaerobic respiration.

## LANGUAGE OF BIOLOGY

activation energy
active site
ADP
aerobic respiration
anaerobic respiration
ATP
cellular respiration
chemical energy
coenzyme
endergonic
energy
enzyme
exergonic
fermentation
high-energy bond
kinetic energy
law of conservation of energy
lock and key hypothesis
potential energy
substrate

## CHECKING YOUR IDEAS

*On a separate paper, indicate whether each of the following statements is true or false. Do not write in this book.*

1. Cellular respiration is an endergonic set of reactions.
2. Enzymes lower required activation energy in cells.
3. All cellular reactions require ATP.
4. Energy for making ATP can come from glucose.
5. The part of the enzyme which combines with the substrate is the active site.
6. More energy is released during anaerobic respiration than during aerobic respiration.
7. When energy changes form, some energy is lost.
8. Enzymes are reusable.
9. ATP is a usable source of chemical energy in cells.
10. A battery not being used has potential energy.

## EVALUATING YOUR IDEAS

1. What are some forms which energy may take? Give an example of energy changing in form.

## CHAPTER REVIEW

2. Which form of energy is most important to living things? Explain how it is used.
3. What is meant by "conservation of energy"? Give an example.
4. Why is heat not a suitable source of activation energy for organisms?
5. Describe the lock and key hypothesis. What traits of enzymes does it explain?
6. Using diagrams, show how an enzyme would operate in (a) the synthesis of a disaccharide and (b) the conversion of a dipeptide to two amino acids.
7. Distinguish between an endergonic reaction and an exergonic reaction.
8. How is ATP used in driving reactions?
9. What remains after a molecule of ATP has been used? What is needed to produce ATP?
10. What are the reactants and products of cellular respiration?
11. How efficient would cells be if the energy from glucose were not transferred to ATP?
12. Describe the ATP-ADP cycle.
13. How is cellular respiration similar to a rock on a hill? How is it different?
14. How is anaerobic respiration less "profitable" than aerobic respiration? Why?
15. How is fermentation in yeasts useful?

## APPLYING YOUR IDEAS

1. Assume that the amount of enzyme in a reaction is kept constant. How would you expect the rate of a reaction to be influenced by adding more substrate? Why?
2. ATP may be considered as the "coins" which the cell uses to pay its debts. Using this analogy, how would you describe glucose? Why?
3. Yeasts can respire both with and without oxygen. Explain why yeasts respiring with oxygen grow and divide more rapidly than yeasts respiring without oxygen.
4. Which has the most potential energy—a diver on a high board, a diver on a low board, or a diver entering the water? Explain your answer in terms of kinetic energy.
5. Glucose is made by producers. How does the producer use that glucose?
6. How is photosynthesis an example of energy transformation (energy changing forms)?

## EXTENDING YOUR IDEAS

1. Conduct an experiment to determine the effect of temperature or pH on the rate at which an enzyme operates.
2. Report to the class on several vitamin-deficiency diseases and their symptoms.
3. Some organisms are bioluminescent (by oh lew muh NEHS uhnt). That is, they produce "cold" light. Find out how these organisms produce light and how the light is useful to them.
4. Louis Pasteur was a versatile scientist. What role did he play in solving the problems of the wine industry?
5. Devise a class demonstration which shows the idea of alcoholic fermentation.

## SUGGESTED READINGS

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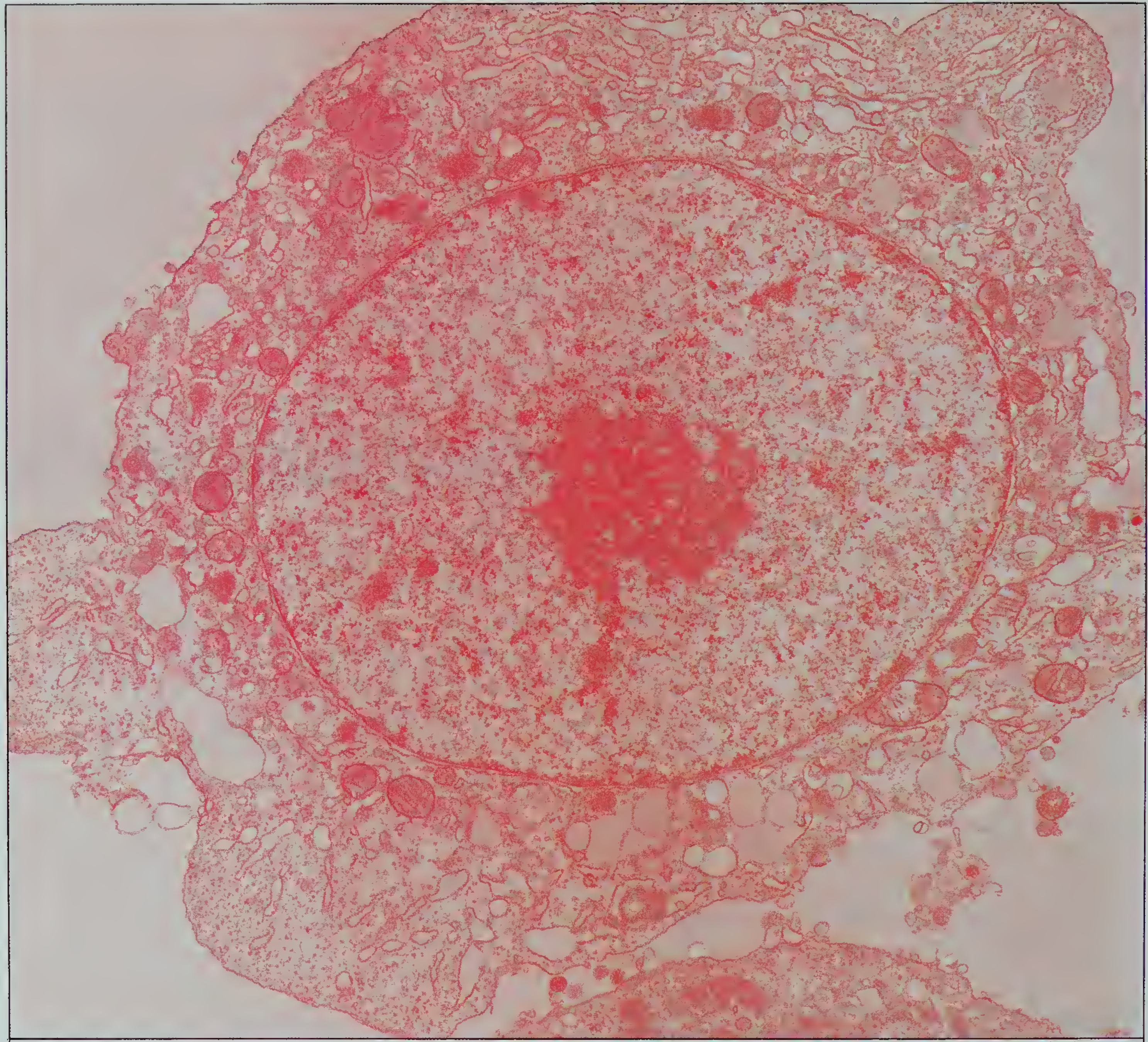

Dr. Judie Walton, Lawrence Livermore National Laboratory

*The cell is the basic unit of life. Different cell parts function in different ways resulting in life processes such as fluid balance and protein production. This liver cell is shown magnified about 4000 times. What cell structures are present in this cell and in other cells? How do the cell parts function? How can cells and cell parts be studied?*

Chapter
5

# CELL STRUCTURE AND FUNCTION

In 1665, Robert Hooke, an English scientist, made important observations. Using an early microscope, he examined razor-thin slices of cork, a plant material. He saw that the cork is composed of many tiny units. Because they reminded him of a honeycomb, he named these units **cells.** Although Hooke did not realize it, he was the first to observe this feature of life.

**GOAL:** You will gain an understanding of the structure and function of the cell.

Robert Hooke, who first observed and named cells, saw only the walls of dead cork cells.

## DISCOVERING CELLS

### 5:1 The Cell Theory

Hooke's discovery of cork cells was the foundation of a major biological theory. The development of that theory, however, took almost two hundred years. Study was limited by poor microscopes. Although later scientists reported finding cells in many plants and animals, they did not realize the importance of the observations. They made no general statements about cells.

When Hooke looked at cork, he saw only dead cells. Only the outer parts, or walls, of the cells were visible. He observed, then, only the borders of hollow compartments. There was certainly no hint that living cells are active and are composed of still smaller parts.

Later discoveries by a number of scientists led to a more accurate picture of a living cell. In the 1830's Robert Brown (1773–1858) determined that a cell contains a central part, or **nucleus** (NEW klee us). It was later reported that cells are not hollow structures. Cells are filled with a thick, jellylike fluid. Matthias Schleiden (SHLI dun) determined that all plants are composed of cells and that cells are the basis of an organism's function. A year later, Theodor Schwann (SHVAHN) determined the same things about animals. In 1858, Rudolf Virchow (FIHR koh) concluded that all cells come from other living cells.

A cell has a nucleus (or nuclei) and is filled with a jellylike fluid.

All organisms are composed of cells.

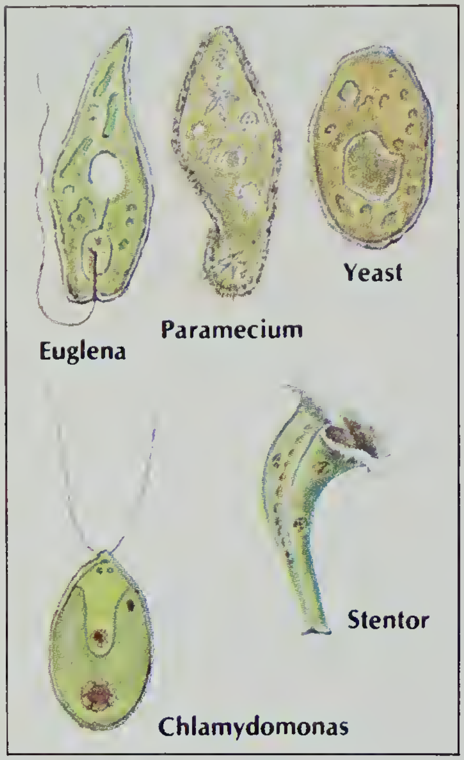

FIGURE 5-1. A unicellular organism is one cell. It performs all life functions. Many organisms are unicellular.

The conclusions made by Schleiden, Schwann, and Virchow are extremely important because they apply to all living things and they have been supported by later findings. These statements form the basis of one of biology's most important concepts, the **cell theory.**

1. All organisms are composed of cells or cell fragments which are the basic units of structure and function.
2. All cells are produced from other cells.

The development of the cell theory is a good example of the interaction of careful observation, interpretation, and curiosity. Why is it called a theory rather than a hypothesis?

## 5:2 Characteristics of Cells

Cells exist in many shapes, such as spherical and cubical. Epithelial cells, cells found in protective layers, are cubical. Some cells, such as the amoeba, have shapes that will change. The surfaces of the cells vary too. Some have rough surfaces; some have extensions and other cell parts coming from their surfaces. A sperm cell has a "tail." Cells also vary in size. Ostrich eggs are as wide as 10 cm; other cells are smaller than half a micrometre. Regardless of shape, surface traits, and size, all cells are alive and are the basic units of life.

All cells perform similar, basic functions.

Many organisms such as bacteria, amoebae, certain algae, and yeasts are **unicellular** (composed of only one cell) organisms (Figure 5-1). More often, however, an organism is multicellular. A **multicellular** organism is composed of many cells. A full grown human contains trillions of these units of life. Both unicellular organisms and cells of multicellular organisms perform the following functions. Most cells get food for energy, rid themselves of wastes (dangerous by-products of chemical reactions), obtain oxygen, and synthesize (SIHN thuh size) (build up) new living material. They also get necessary chemicals, regulate water balance, react to changes in the environment, and produce other cells.

How are all these life activities and processes carried out? The answer can be found by examining the composition of cells and learning about those parts common to most cells.

### REVIEWING YOUR IDEAS

1. Why did Hooke see only the outer walls of cells?
2. Describe the findings of Schleiden, Schwann, and Virchow.
3. State the cell theory.
4. Distinguish between unicellular and multicellular organisms.
5. List some functions of cells.

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John Hanson/OSU

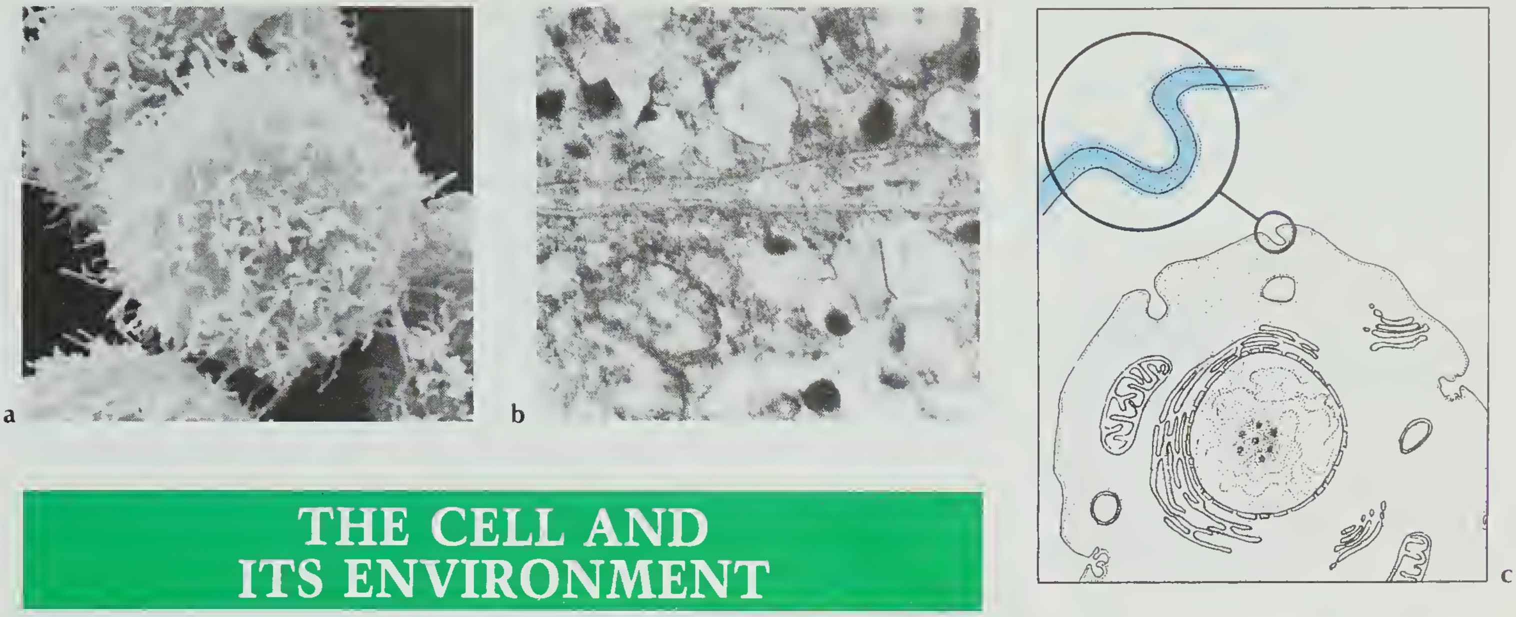

FIGURE 5-2. (a) A scanning electron micrograph of a hamster cell magnified 3500 times shows surface properties of the cell membrane. (b) Magnified 23 000 times, a cell membrane can be seen as two layers. (c) The two layers of the cell membrane are shown in relation to the cell.

# THE CELL AND ITS ENVIRONMENT

Each cell, whether an entire organism or a small part of a larger living system, is in an environment. An amoeba may be in a pond. A kidney cell may be surrounded by blood. Wherever the cell is, it must exchange materials with its moist environment.

## 5:3 Cell Membrane

Each cell has a boundary which separates it from neighboring cells or its environment. This boundary is called the **cell membrane.** The cell membrane holds the cellular contents together. It also determines the cell's shape and protects the cell.

A cell is enclosed by a cell membrane.

With a light microscope, the cell membrane appears as a thin, single line. The electron microscope shows the membrane to consist of two layers (Figure 5-2). Analysis shows that the membrane is composed of proteins and lipids in roughly equal amounts. Studies suggest that some of the proteins are partly or totally embedded in the lipid portion. Other proteins seem to lie on the surface of the lipids (Figure 5-3). The position of the proteins and lipids may change slightly from time to time. This model of membrane structure is called the **fluid mosaic model.**

The cell membrane is composed of protein and lipid.

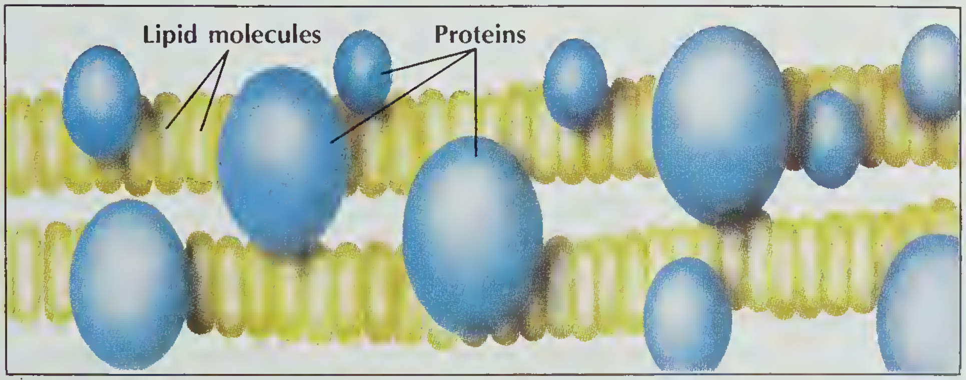

FIGURE 5-3. The fluid mosaic model of membrane structure shows proteins which move in the layers of lipid molecules.

Membranes of many other cell parts have a structure similar to the cell membrane. The differences may be due to the kinds and locations of proteins in each membrane.

Proteins in the cell membrane play both structural and functional roles.

Proteins in the membrane play both a structural and functional role. Many of them are enzymes (Section 4:3). Some act as "markers" that are recognized by chemicals produced by other cells. Others help certain particles pass across the membrane. Some of the openings, or pores, in the membrane seem to be lined with protein.

Cell membranes are active and flexible.

The membrane is an active part of the cell. Membranes of many cells are very flexible and can change shape because the lipids and proteins of membranes can move. Movement can be studied and observed only with living cells. When cells are removed from an organism and stained for microscopic study, they die. Some cells you will see in the laboratory will be dead. Keep in mind that what is seen in prepared slides is somewhat artificial.

## 5:4 Diffusion

The cell membrane is the "gatekeeper" of the cell.

Besides being a structural boundary, the cell membrane is also the "gatekeeper" of a cell. Many cell functions (Section 5:2) are related to the cell's environment. For example, how do amino acids that the cell combines into protein get into the cell? What is the source of food molecules "burned" for energy within the cell? What happens to the carbon dioxide produced during the "burning" process? What happens to waste products? These and other materials must enter and leave cells through the cell membranes.

It is important that only *certain* materials pass through the cell membrane. Only those materials which must be exchanged with the environment should enter and leave. Unnecessary and harmful substances must be kept out. Important and needed substances must stay in if the cell is to survive. A membrane, such as the cell membrane, which allows only certain materials to pass through it is called a **semipermeable** (sem ih PUR mee uh bul) **membrane.** How do materials pass through a semipermeable membrane?

The cell membrane is semipermeable.

If you place some crystals of blue copper sulfate in a beaker of water, you will see evidence of an important physical process. At first, the water will be colorless and the crystals will settle to the bottom of the beaker. Several hours later you will see that the water has turned blue and the crystals have disappeared. What has happened?

When copper sulfate is placed in water, its ions begin to separate from each other. The ions have kinetic energy (energy of motion) (Section 4:1). They move about randomly. As a result,

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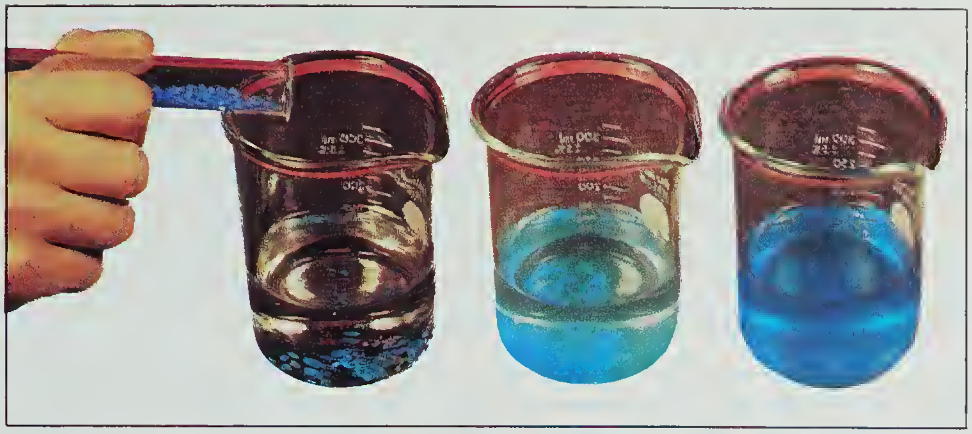


**FIGURE 5-4. Copper sulfate, a blue crystal, diffuses through water distributing copper and sulfate ions evenly throughout. The solution turns bluer as diffusion proceeds.**

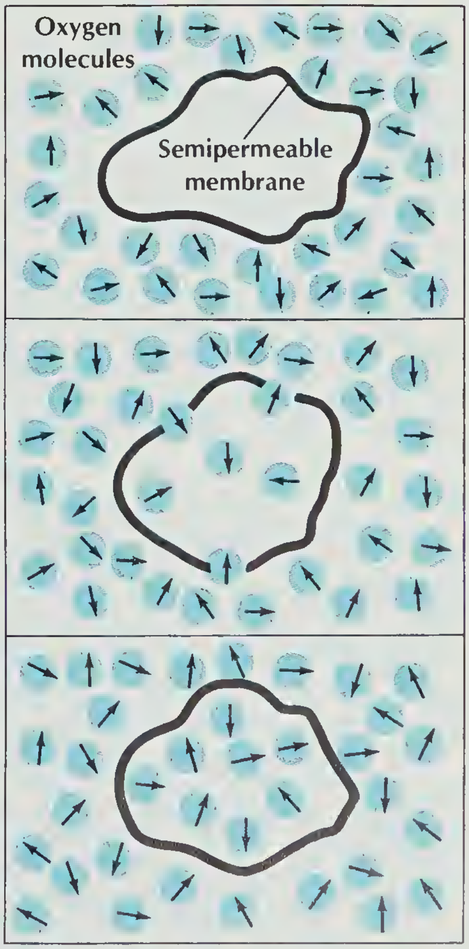
they collide with each other, the molecules of water, and the sides and bottom of the beaker. Each time a collision occurs, ions bounce off and move in new directions. Random movement results in a uniform distribution of ions throughout the water.

The water appears blue because there are equal numbers of copper ions in any given region at any given time. This random movement of ions (and other particles) caused by kinetic energy is called **diffusion** (dihf YEW zhun). Diffusion results in the spreading out of particles. The particles become distributed evenly in all the available space. After the ions become distributed evenly, they continue to move, but the same number of ions enters a certain area as leaves the area.

Suppose a cell is surrounded by oxygen molecules and the membrane is permeable to oxygen. Because the oxygen molecules are in random motion, they bump against each other and the membrane of the cell. The membrane is permeable to oxygen. Thus, the molecules can pass through it into the cell. As oxygen molecules enter the cell, their movement results in more collisions. Random movement across the membrane occurs in both directions. At first more oxygen molecules enter the cell than leave the cell. Later the oxygen molecules become distributed evenly inside and outside the cell. This balance is called a **dynamic equilibrium** (di NAM ihk·ee kwuh LIHB ree um). After dynamic equilibrium is reached, molecular motion continues, but the number of molecules entering and leaving the cell is equal.

This random movement of molecules shows the importance of diffusion in living systems. Some needed materials may enter a cell by diffusion. Also, as some by-products of cellular activities build up in a cell, their random motion may move them out. *In either case, a substance moves from a region of greater concentration to a region of lesser concentration.* Once equilibrium occurs, the substance remains in equal concentration on both sides of the membrane although movement still occurs.

**FIGURE 5-5. Diffusion of oxygen molecules into a cell occurs as the oxygen molecules move from a region of greater concentration to a region of lesser concentration. Dynamic equilibrium results.**



## 5:5 Osmosis

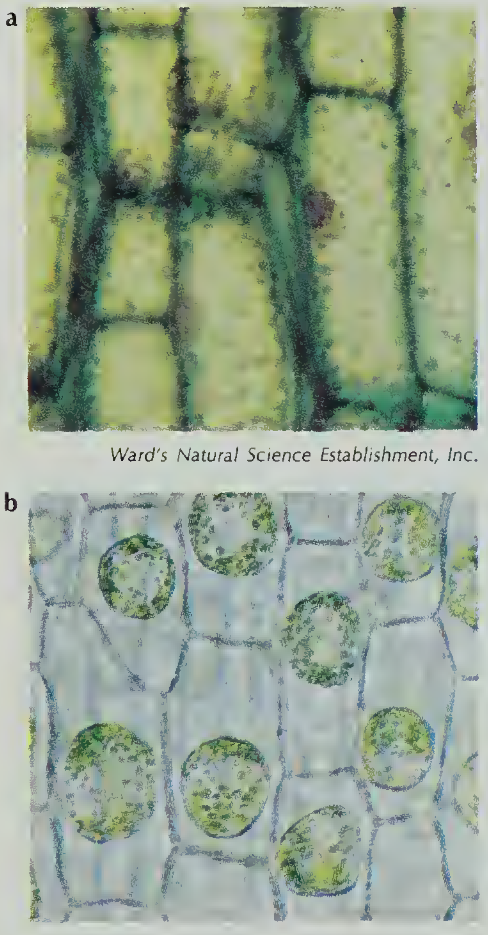
Diffusion of water through a semipermeable membrane is called osmosis.

Water is important to living systems. Water makes up a great part of an organism's mass (seventy percent or more) and is also the major part of each cell's environment. Movement of water into and out of cells is so common that it is given a special name—osmosis (ahs MOH sus). **Osmosis** is the diffusion of water through a semipermeable membrane. Water can pass in either direction across the membrane.

Osmosis results in a state of balance.

Like diffusion, osmosis is the random movement of particles that results in a state of balance. Water molecules become balanced on both sides of a membrane. The water in a red blood cell is in dynamic equilibrium with the water in the bloodstream. However, if the cell is removed from the blood and placed in pure water, equilibrium is destroyed. The blood cell contains water and other substances, but the surrounding water has no other substances in it. Thus, the concentration of water inside the cell is less than the concentration of water outside the cell. As a result, more water molecules enter the cell than leave the cell. More molecules enter the cell because more hit the membrane from the outside than from the inside. Thus, the cell's water balance is achieved.

**FIGURE 5-6. (a) In fresh water, the *Elodea* cells are in osmotic balance with the environment. (b) In salt water, water moves out of the cells. As a result, the contents shrink to the center of the cell.**



Ward's Natural Science Establishment, Inc.

Grant Heilman

Water entering the red blood cell causes it to swell. If equilibrium is not reached, the cell will continue to swell. So much water may enter the cell that it bursts. Therefore, it is important that cells be in osmotic (ahs MAHT ihk) balance with their environment. **Osmotic balance** is a kind of dynamic equilibrium. It occurs when the amount of water entering and leaving a cell is equal.

*Elodea* (ih LOHD ee uh) is a freshwater plant often seen in home aquariums. The cells of *Elodea* contain water and dissolved materials, but the freshwater environment consists mainly of water molecules. Therefore, in its usual environment, water tends to enter the cells of this plant. Because the pressure of the cell wall balances the pressure of water inside the cell, osmotic balance is reached. Pressure is exerted by the cell wall because the wall is inflexible.

What would happen if an *Elodea* leaf were placed in a salt-water solution? The concentration of water molecules inside the cells would then be greater than outside the cells. Water molecules would leave the cells faster than they would enter. Such loss of water in a cell causes the cell contents to shrink (Figure 5-6) and is called **plasmolysis** (plaz MAHL uh sus). The Elodea plant would appear to be wilted because the cell walls cannot hold up the plant. Prolonged plasmolysis or a large water loss results in death to the cells and can result in death to the entire plant.

## 5:6 Passive Transport

Osmosis of water and diffusion of other particles are important for their passage across the cell membrane. Movement of these materials into and out of the cell is caused by their kinetic energy and random motion. The particles may move through pores in the membrane. The cell has no active role (does no work) in moving the particles. Because no extra energy is needed in diffusion or osmosis, this type of movement is called **passive transport.**

In some cases, even if a particle is in greater concentration on one side of the membrane than the other, it cannot easily cross the membrane by diffusion. It may be too large to get through the pores. Maybe it is not soluble in the lipid part of the membrane. Many such particles, sugars, for example, can move across the membrane by another form of passive transport.

Recall that some of the proteins in the cell membrane play a role in speeding the movement of particles across it (Section 5:3). The models used to explain the movement include proteins called carrier molecules. **Carrier molecules** combine with certain particles and help them to pass across the membrane. Exactly how this process occurs is not known. Evidence indicates that when the particle combines with the carrier, the carrier's shape is changed. The change in shape somehow "pushes" the particle across the membrane (Figure 5-8). Like diffusion, this process involves the movement of substances from regions of greater to lesser concentration. Because a carrier helps (facilitates) the process, it is called **facilitated diffusion.** Glucose enters red blood cells by facilitated diffusion.

Passive transport involves net movement of particles from a region of greater to lesser concentration. The kinetic energy of the particles determines the direction in which the particles move.

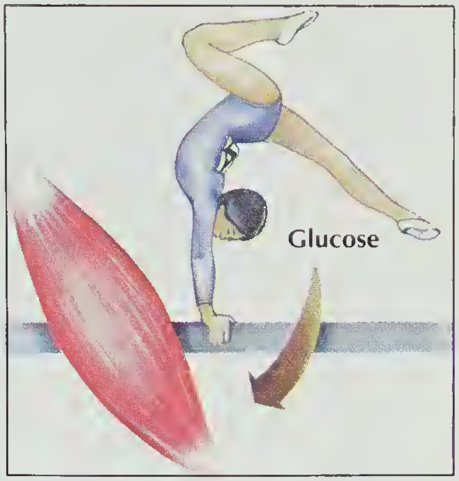


**FIGURE 5-7. Glucose moves into muscle cells by facilitated diffusion, a kind of passive transport.**

In passive transport, no added energy is used in exchanging materials.

In facilitated diffusion, carrier molecules help move particles from a region of greater to lesser concentration.

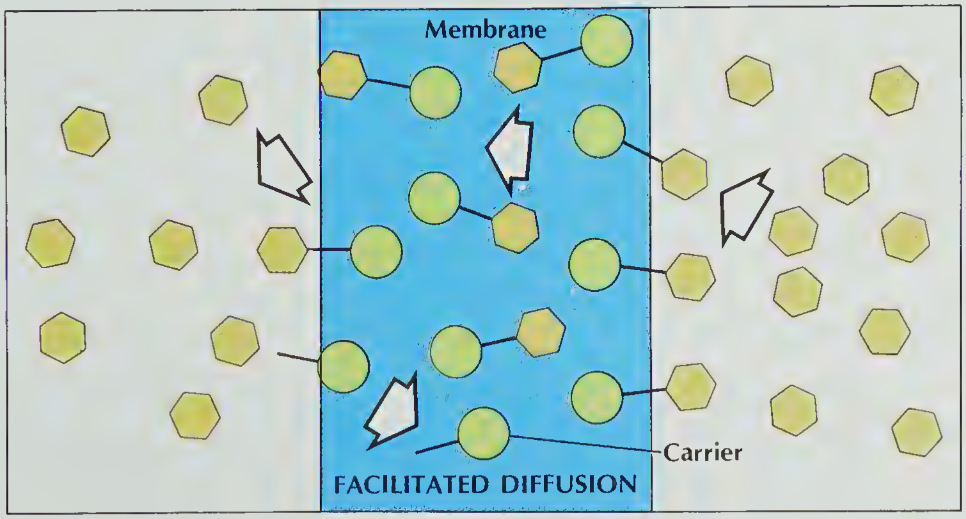


**FIGURE 5-8. In facilitated diffusion, carriers aid (facilitate) the movement of other molecules across the membrane. Here the molecules are being moved from right to left. The carriers then return to move other molecules across.**

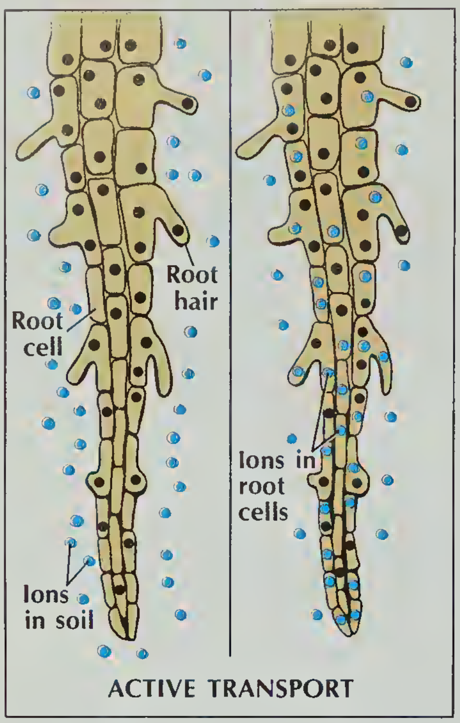


**FIGURE 5-9. By active transport, root cells accumulate ions in concentrations greater than in the soil. Active transport requires energy.**

## 5:7 Active Transport

Sometimes a cell must move particles from a region of lesser to greater concentration. The cell must use energy to counteract the kinetic energy of the particles. (The cell's energy causes the movement of the particles to be less random.) The cell plays an active role and does work. Because extra energy is required to move the particles, this type of movement is called **active transport.** The energy of ATP (Section 4:7) is used. Active transport also involves carrier molecules.

A cell can rid itself of harmful particles by active transport. For example, some cells of the kidney actively transport wastes out. Waste materials must be removed. Some wastes (even in small amounts) would poison an organism. Active transport maintains a greater concentration of the waste materials outside the kidney cells than inside the cells.

Active transport also may work to bring extra particles into the cell. For example, root cells of plants bring in and retain needed mineral ions from the soil. There are more ions in the root cells than in the soil, but ions continue to enter the cells by active transport. Use of energy by these cells prevents the natural diffusion of these ions out of the cells (Figure 5-9).

## 5:8 Factors of Permeability

Small particles pass through the cell membrane more easily than large particles.

Fat-soluble particles readily pass through the cell membrane.

The ideas of how transport occurs fit with the model of cell membrane structure (Section 5:3). You can see why membranes are semipermeable. In general, smaller particles pass through the membrane more easily than do large ones. These small particles may pass through the pores or through the spaces between lipid molecules. Substances which are soluble in fat pass through the cell membrane readily. Remember that the membrane contains lipid. Fat-soluble substances may slide between the protein molecules and then dissolve in the lipid portion of the membrane. Later they pass into (or out of) the cell.

Cells differ in their permeability.

Different cells are permeable to different particles. The structure of each type of cell membrane varies depending upon the proteins present. Size of pores may vary and different carriers exist. Also, a given cell may be more or less permeable to a certain particle at different times. Recall that the position of both proteins and lipids may change.

## 5:9 Endocytosis

Some materials which are too large to pass through the cell membrane by passive or active transport can enter a cell in another way. **Endocytosis** (en duh si TOH sus) is a process in which a cell uses energy to surround and take in large particles.

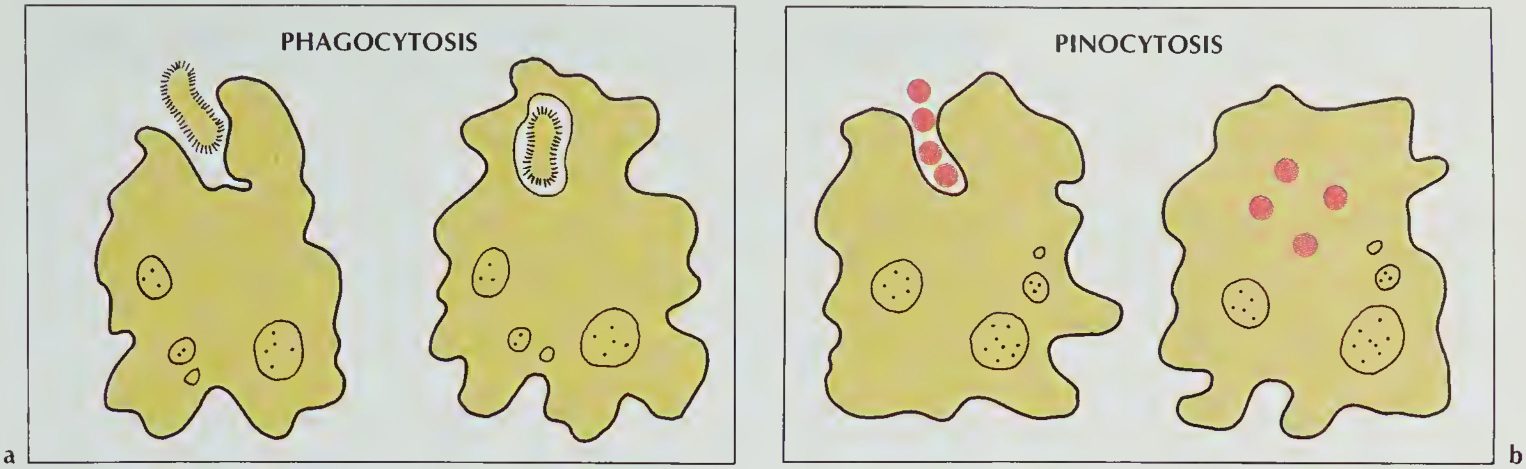


**FIGURE 5-10.** (a) In phagocytosis, the cell surrounds the particle or organism being taken in. (b) In pinocytosis, the cell forms channels through which liquids and small particles are taken in.

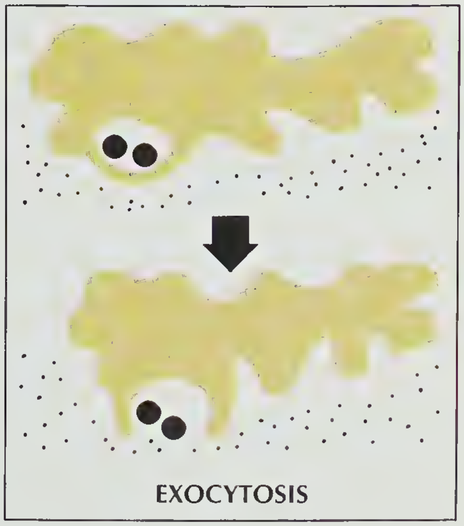
Many unicellular organisms, such as an amoeba, depend on smaller organisms for food (Figure 5-10). After detecting food, an amoeba's cell membrane engulfs (flows over and encloses) the food organism. That portion of the membrane then breaks away and moves to the cell's interior. The food contained within it will later be digested (Section 5:13). The trapping of a solid in this way is called **phagocytosis** (fag uh si TOH sus). Phagocytosis requires energy because work is done in capturing the food and in "repairing" the cell membrane where the part pinched off.

Cells of multicellular organisms also use phagocytosis. For example, certain cells in your blood (white cells) are very much like amoebae. These cells engulf and digest bacteria and other foreign particles which invade the body. Thus, the white cells are a line of defense against disease.

**Pinocytosis** (pihn uh si TOH sus) is another type of endocytosis. Liquids and small particles are taken into a cell by pinocytosis. Pinocytosis involves the formation of channels through which the liquids and small particles enter a cell. The channeled substance then becomes surrounded by the membrane. The substance is later digested within the cell.

A reverse process is used to rid some cells of wastes or even useful substances needed elsewhere. The substances, enclosed in a membrane, move toward the cell membrane. The two membranes fuse and the materials are expelled from the cell. This process is called **exocytosis** (ek soh si TOH sus).

**FIGURE 5-11.** Exocytosis is a process in which substances are expelled from a cell.



## REVIEWING YOUR IDEAS

6. What is the cell membrane? Of what is it composed?
7. What is diffusion? What is the name for the balance that results from diffusion?
8. What is osmosis?
9. Compare diffusion and facilitated diffusion.
10. Distinguish between passive and active transport.
11. Distinguish between endocytosis and exocytosis.

## INSIDE THE CELL

Once substances enter a cell, what does the cell do with them? How and where does the cell assemble new living materials or "burn" food for energy? Where in the cell do wastes arise? The answers are to be found in a study of the cell's interior.

### 5:10 Protoplasm

Protoplasm is the living, jellylike portion of cells.

The "living stuff" of cells was first described in the 1830's (Section 5:1). Hooke did not see it because the cork cells he saw were not alive. This "living stuff" of cells, the thick, jellylike substance which makes up most of each cell, is **protoplasm** (PROHT uh plaz um).

Two regions of protoplasm exist in most cells—cytoplasm and nucleoplasm.

Protoplasm consists of two regions. Inside the nucleus it is called **nucleoplasm** (NEW klee uh plaz um) and outside the nucleus it is called **cytoplasm** (SITE uh plaz um). These terms are based only on location in the cell.

The composition of protoplasm is constantly changing.

Protoplasm is about 70% water and about 30% protein, fats, carbohydrates, and small amounts of mineral ions. The composition of protoplasm varies. Thousands of different substances are brought into or made by a cell and are changed from second to second. A molecule of sugar now existing in one of your cells easily could be converted to carbon dioxide by the time you finish reading this sentence. Protoplasm changes constantly. Chemical reactions within a cell both build up and tear down many complex molecules. The total of the reactions is called **metabolism** (muh TAB uh lihz um).

Metabolism is the total of a cell's chemical reactions.

Metabolism involves a variety of reactions. Some of them, such as dehydration synthesis or hydrolysis (Section 3:17), occur in one step. Often a complex set of reactions is involved in a metabolic change. Think of the many separate steps of cellular respiration (Section 4:8). Photosynthesis (Chapter 21) is another complex set of reactions.

Not all the reactions of metabolism occur in the cytoplasm. Some take place in specialized structures within the cytoplasm.

**FIGURE 5-12.** An organism's proper functioning is the result of chemical reactions that take place in the protoplasm of the cells.

## 5:11 Organization in Cells

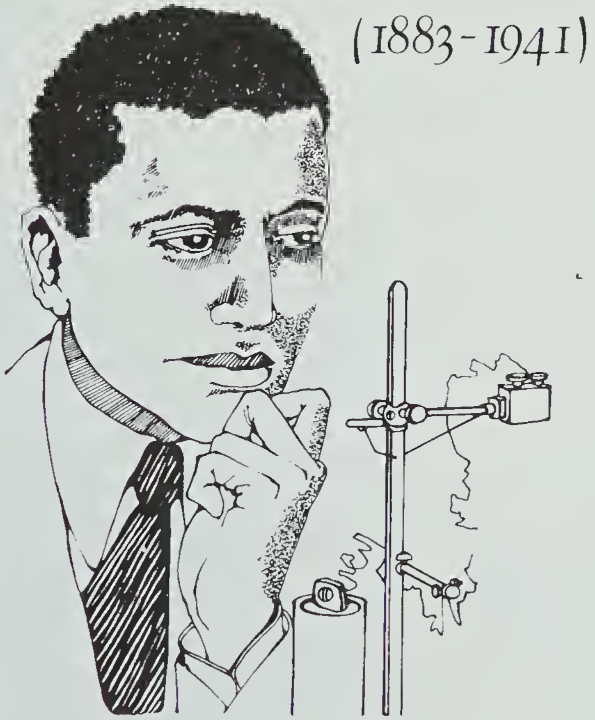
In Chapter 1, you learned how cells were organized into tissues and organs. But, for cells to perform their many functions, they too must be organized. Certain jobs are carried out by specific cell parts called **organelles** (or guh NELZ), located in the cytoplasm. An organization of parts each doing specific jobs is known as **division of labor**. Division of labor occurs among the cell's organelles. However, a cell survives only if all of its parts work together.

Organelles are specialized for cellular functions. Division of labor occurs among the organelles.

Much of what is known about cell structure has been learned from studies with the electron microscope (Section 2:12). Biochemical analysis also has been used to study the function of cell parts. The descriptions of cell parts given here are based on these methods. Keep in mind that many structures are either not clear or not visible with the light microscope. So do not expect to see all the parts described in this chapter when you view cells in the laboratory.

### PEOPLE IN BIOLOGY

As a teenager, Earnest Just left the South with few academic skills other than reading. He completed high school and college in New Hampshire, graduating with honors, and soon began teaching in Washington DC. His interests in cell biology led him to the University of Chicago, where he completed his doctorate in 1916. The rest of his life was devoted to both research in cell biology and embryology and to teaching.



Earnest Everett Just

In the 1920's and 1930's, Just took some unpopular stands concerning the roles of various cell parts. He thought that cell membranes were active parts of cells, not just coverings. He also felt that the cytoplasm was as important as the nucleus in determining the cell's activities. (Remember that much of the information we have today about cells was not known at that time.) Because of his unpopular views, even though later shown to be correct, Just and his work were not fully appreciated in his lifetime. He did, however, publish numerous articles and authored two books. In 1915, he was the first person to receive the NAACP Spingarn Medal for "highest achievement. . . . in an honorable field of human endeavor."

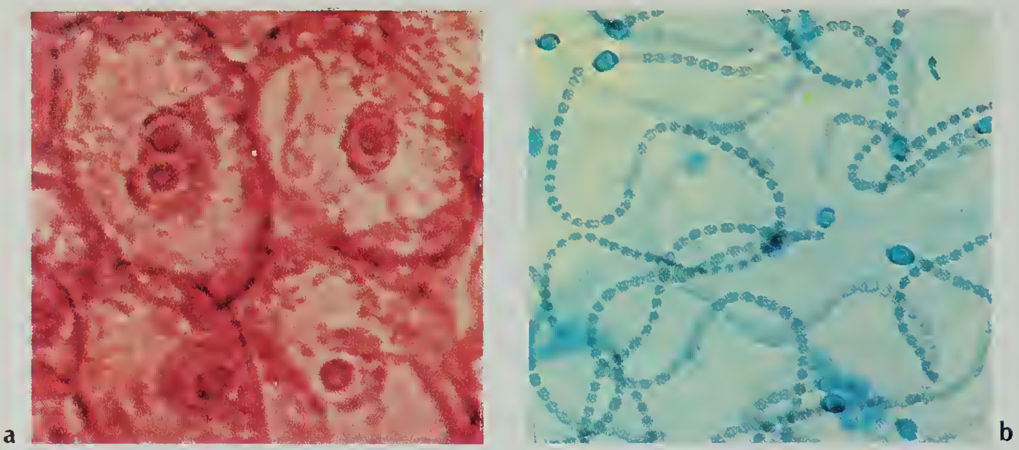


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**FIGURE 5-13.** The biggest division among cells is between (a) eukaryotic cells, and (b) prokaryotic cells. Eukaryotic cells have nuclei and membrane-bound organelles. Prokaryotic cells lack these structures.

## 5:12 Cell Parts of Eukaryotes

Eukaryotic cells have nuclei and membrane-bound organelles. Prokaryotic cells lack nuclei and membrane-bound organelles.

Blue-green algae and bacteria are prokaryotes. All other cells are eukaryotes.

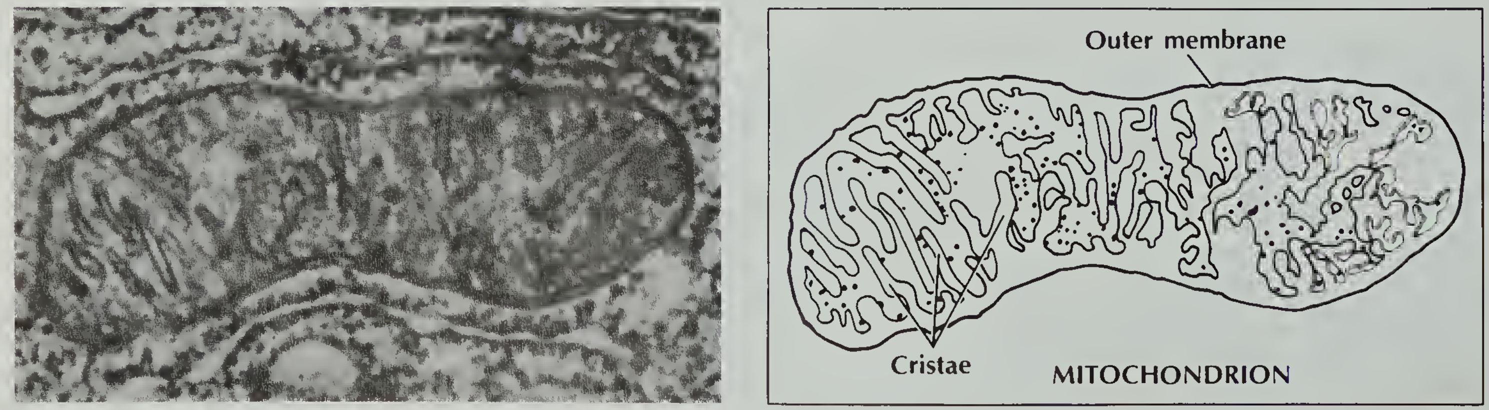
Cells of all organisms fall into one of two broad groups. They are either eukaryotes (yew KER ee ohtz) or prokaryotes (proh KER ee ohtz). **Eukaryotes** are cells that are more complex and contain a distinct nucleus surrounded by a membrane. Eukaryotes also contain organelles enclosed by membranes. **Prokaryotes** lack nuclei and other membrane-bound organelles. Bacteria and blue-green algae are prokaryotes. All other cells are eukaryotic. Specialized cell parts presented in this section are parts of eukaryotic cells. Prokaryotes only have a few of these cell parts (with different structures). Structure of prokaryotes will be studied in Chapter 13.

Mitochondria (singular, mitochondrion) are the "powerhouses" of the cell.

**Mitochondria** (mite uh KAHN dree uh) are organelles scattered through the cytoplasm. They vary in size, often are cigar-shaped, and have a double-layered membrane with the inner layer folded inward. The folds are called **cristae** (KRIS tee). The central cavity is filled with a fluid (Figure 5-14).

More mitochondria are found in cells requiring great amounts of energy than in other cells. Mitochondria are involved with energy. Because much of aerobic respiration occurs in the mitochondria, they often are called the "powerhouses" of the cell. They are the sites of production of most of the cell's ATP.

**FIGURE 5-14.** A mitochondrion is a double-membraned organelle which releases energy in a usable form (ATP) in a cell. This mitochondrion is shown magnified about 40 000 times.



**Endoplasmic reticulum** (en duh PLAZ mihk · rih TIHK yuh lum) is a network of fluid-filled, tubelike structures found in most eukaryotic cells. It is often called ER. These tubes connect with one another, often ending in "blind alleys." In some cells, portions of the network are connected with the nuclear membrane. The endoplasmic reticulum acts as a cellular "subway" or "canal system" that transports materials within cells.

Some of the cell's ER has a smooth surface and is called *smooth ER.* The structure of the ER's membrane is similar to that of the cell membrane. Some of the proteins in smooth ER membrane function as enzymes needed for making lipids (Section 3:14).

**Ribosomes** (RI buh sohmz) are tiny spherical organelles most often located on the surface of ER. (Such ER, because of its "bumpy" surface, is called *rough ER.*) Some ribosomes are scattered through the cytoplasm. These bodies, composed mainly of RNA, are the sites of protein synthesis. Proteins may pass from the surface of the ribosomes into the endoplasmic reticulum for transport within the cell.

**Golgi** (GAWL jee) **bodies** are structures in the cytoplasm that usually consist of a stack of flattened, slightly curved tubes with saclike ends. When seen in a section, Golgi bodies resemble ER except that the tubes of the Golgi do not appear to be connected to each other. Golgi bodies are involved in the storage and **secretion** (sih KREE shun) (pouring out) of chemicals from the cell. These chemicals may affect other parts of the body or other organisms. Digestive juices are cell secretions that affect other parts of the organism. A snake's venom is a secretion that affects another organism.

Barbara Stevens

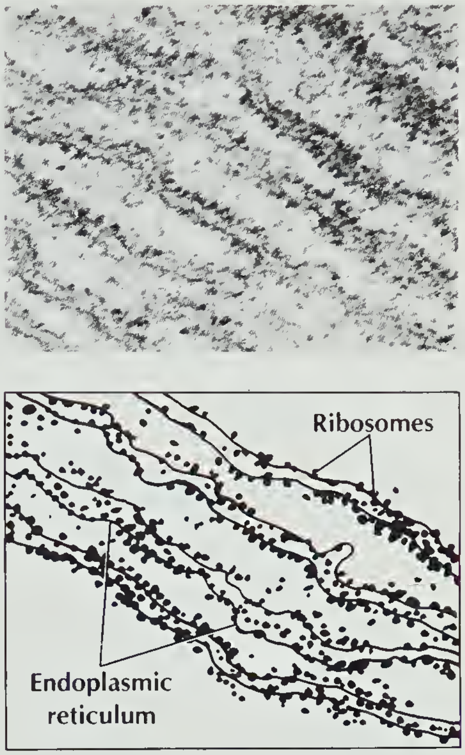
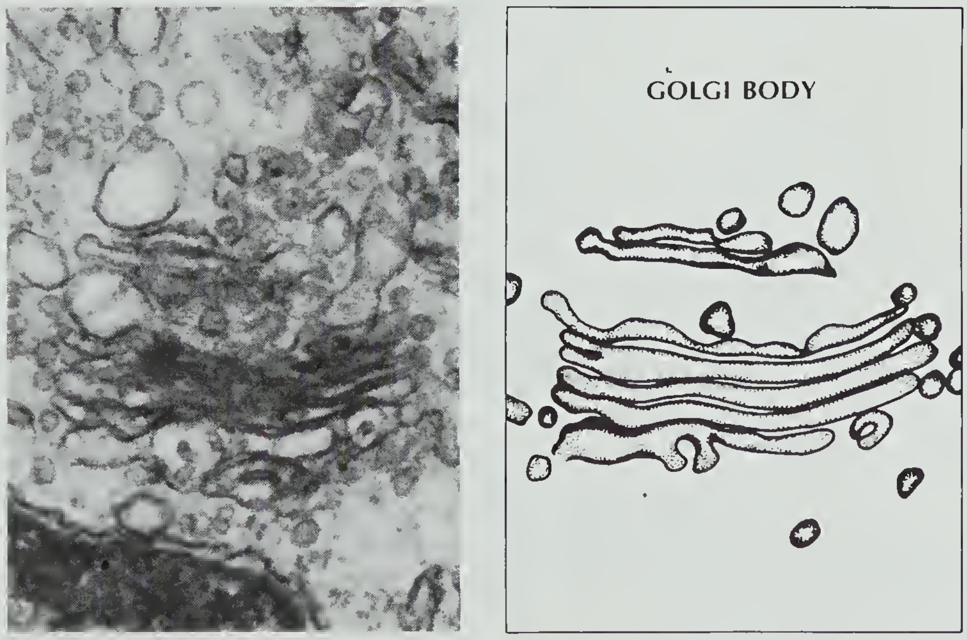


**FIGURE 5-15. Cellular materials are thought to be transported in the tubes of endoplasmic reticulum. Proteins are synthesized on ribosomes. This ER is shown magnified about 40 000 times.**

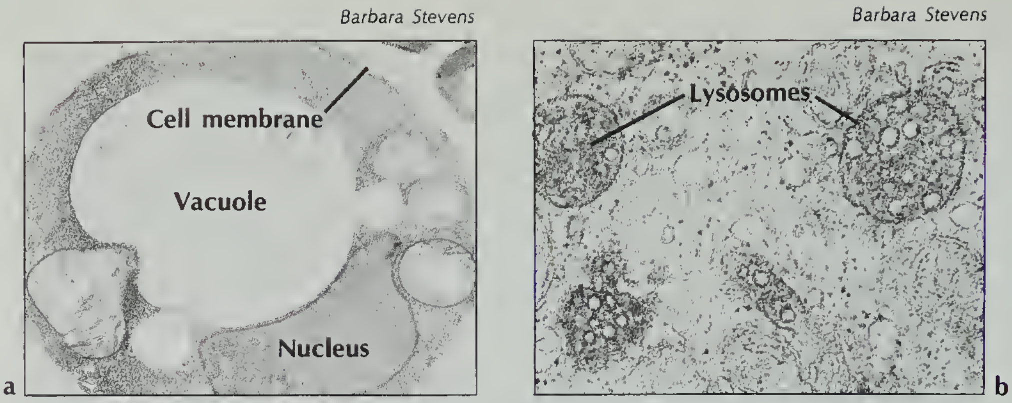
Golgi bodies function in the storage and secretion of cellular chemicals.



Dr. Judie Walton,
Lawrence Livermore National Laboratory

**FIGURE 5-16. Golgi bodies help manufacture and store molecules which later are secreted from cells. Golgi bodies are shaped like stacked plates. This Golgi body is shown magnified about 54 000 times.**

FIGURE 5-17. (a) Most vacuoles function in storage. In this cell, one vacuole takes up most of the space inside. (b) Lysosomes contain chemicals which hydrolyze food molecules. These lysosomes are shown magnified 25 000 times.



Vacuoles may be used for storage of materials.

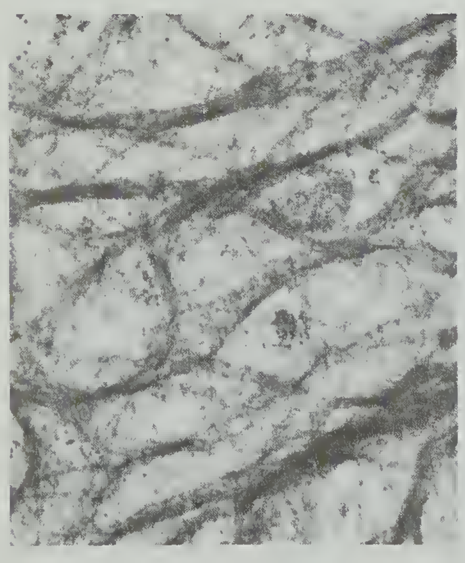
**Vacuoles** (VAK yuh wohlz) are clear, fluid-filled sacs within cells. Many vacuoles are used for the storage of food, water, and minerals. In some plant cells the vacuole may be the prominent structure. Certain unicellular water organisms have vacuoles which serve as pumps for removing excess water. Such water-removing structures are called **contractile** (kun TRAK tul) **vacuoles** (Section 18:7).

Lysosomes contain enzymes which hydrolyze large molecules.

**Lysosomes** (LI suh sohmz) are small, spherical organelles that contain digestive enzymes. They are found mostly in animal cells. The enzymes break down large molecules brought into the cell by phagocytosis.

Lysosomes sometimes digest other cell parts. "Worn out" cell parts are broken down and removed from cells. Also, some parts may be digested to provide energy during starvation. If lysosomes break, the enzymes may even destroy the cell itself. "Worn out" cells may be removed in this way. Normally, the cell is protected from the digestive enzymes by the lysosome's membrane.

FIGURE 5-18. Microfilaments are threadlike structures composed of protein. These bundles of microfilaments are shown magnified about 11 500 times.



Dr. Judie Walton, Lawrence Livermore National Laboratory

**Microfilaments** are long, thin threadlike structures that have been found in a variety of cells. They are composed of protein and are involved with movement. Contraction of skeletal muscle (Chapter 28) depends upon microfilament movement. They also function in other ways such as locomotion of an amoeba or in causing changes in a cell's shape.

**Microtubules** are long, thin structures that provide support and shape to the cell. They are hollow rods composed of protein. Often microtubules are found just beneath the cell membrane where they help maintain the cell's structure. Microtubules also help with the movement of cell parts within the cell. They are important structures in moving genetic material in cell division (Section 6:6) and also they are involved in locomotion of some cells (Section 5:14).

Some microtubules are permanent parts of cells. Most are built up from protein within the cell when needed. They are then torn down and their protein can be reused later in the formation of other microtubules.

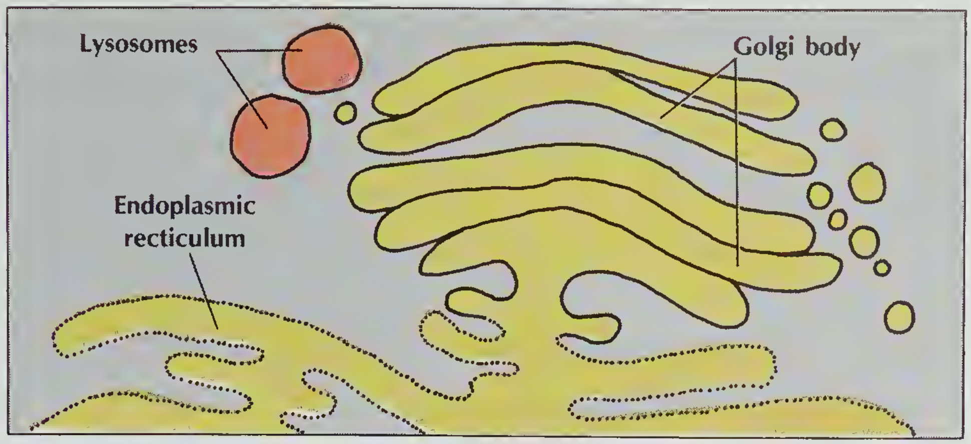


**FIGURE 5-19.** Because endoplasmic reticulum, Golgi bodies, and lysosomes work together, they are sometimes thought of as a complex.

## 5:13 Interaction of Cell Parts

Cell parts interact in carrying out cell processes.

Study of how lysosomes do their job shows the interdependence of cell parts. The enzymes in lysosomes are proteins and are manufactured on ribosomes. From there they may pass into the rough endoplasmic reticulum. From time to time, the endoplasmic reticulum may form temporary connections with the Golgi bodies. Thus, the enzymes can pass from the endoplasmic reticulum to the Golgi bodies. The enzymes accumulate in the ends of the Golgi body tubes which enlarge and pinch off as lysosomes.

Enzymes in lysosomes are manufactured on ribosomes. They travel to the Golgi bodies via the ER.

When a cell traps food by phagocytosis (Section 5:9), it enters the cell in a food vacuole. (The membrane of the vacuole came from the cell membrane.) The food vacuole may fuse with a lysosome and the enzymes in the lysosome digest the food into small molecules. The small molecules may then diffuse across the membrane of the vacuole into the cytoplasm. They can be used for energy or as building blocks of cell parts. Undigested particles remain in the vacuole and leave the cell by exocytosis (Section 5:9).

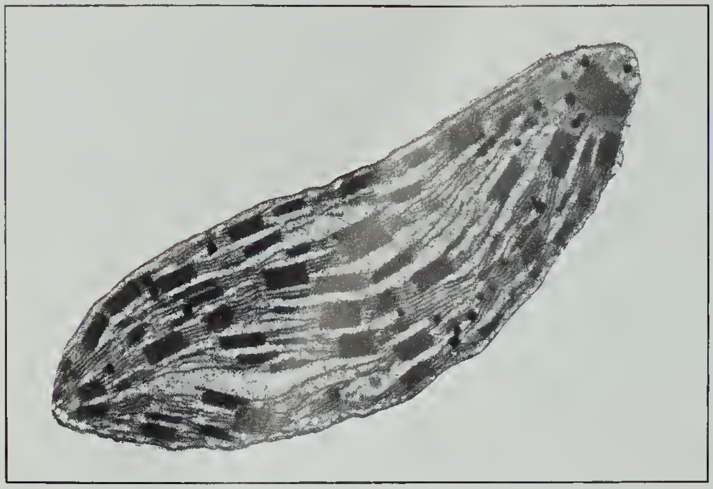
Secretion of chemicals from the cell also involves interdependence of cell parts. Many secretions are proteins which may come to the Golgi bodies from the ribosomes through the endoplasmic reticulum. In the Golgi body other chemicals such as carbohydrates may be added to the protein. These secretions then may be pinched off the ends of Golgi bodies in small packets. The packets then can fuse with the cell membrane and pour their contents out of the cell.

Packets of secretions are formed from the Golgi bodies.

## 5:14 Other Eukaryotic Cell Parts

The cell parts studied so far are found in most eukaryotic cells. Some other parts, though, are found in only some kinds of cells.

Grant Heilman



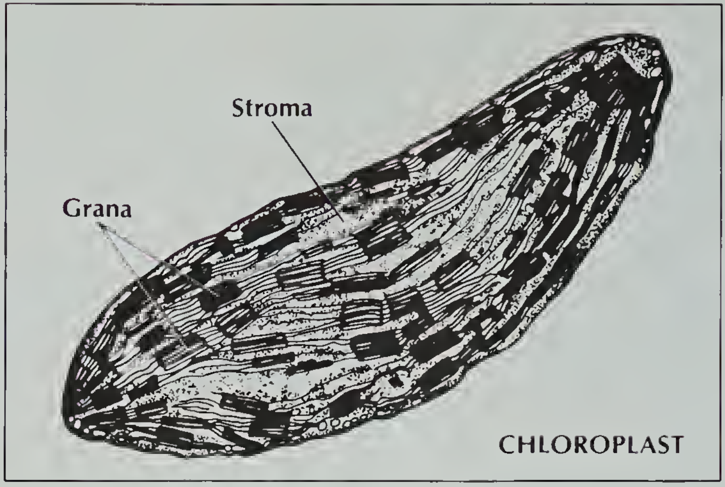


**FIGURE 5-20. Chloroplasts are organelles that function in photosynthesis. This chloroplast is shown magnified about 25 000 times.**

Photosynthesis occurs in chloroplasts.

Green plant cells and most algae contain structures called **plastids** (PLAS tudz). The most common plastids are **chloroplasts** (KLOR uh plastz) which contain the chlorophyll needed for photosynthesis. A chloroplast has many stacks of platelike structures called **grana** (GRAY nuh) (Figure 5-20) located in a liquid. The liquid is called **stroma.** Light energy for photosynthesis is trapped by the grana. Glucose is made in the stroma (Chapter 21).

Other types of plastids contain pigments which aid chlorophyll in trapping solar energy. Some plastids make and store starch and fats.

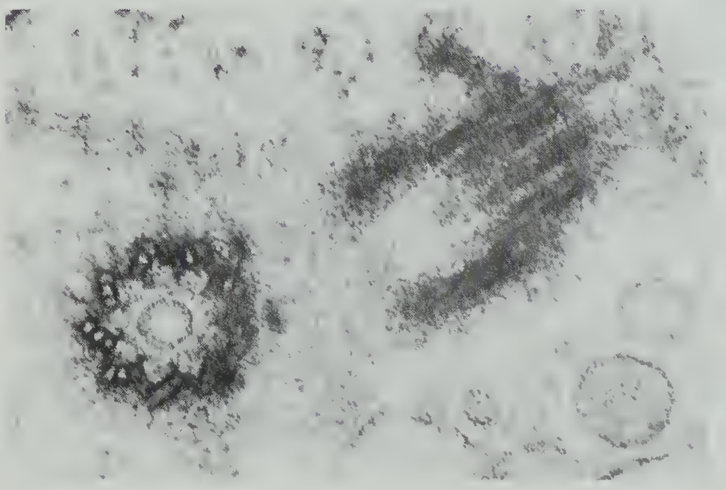
Cell walls support and give shape to cells of algae, fungi, and plants.

Cells of plants, fungi, and algae have a boundary, called the **cell wall,** outside the cell membrane. The cell wall is composed of cellulose or other carbohydrates (Section 3:13). A cell wall gives structure and shape to individual cells and helps support a plant so that it grows upright.

Centrioles function in the division of animal cells.

Cells of animals and of some algae and fungi contain a pair of organelles called **centrioles** (SEN tree olz) which play an important role in cell division. Centrioles come in pairs and are found near the nucleus. Each centriole is composed of nine sets of microtubules (Section 5:12) arranged to form a circle. Each set is

**FIGURE 5-21. Centrioles are found mostly in animal cells and are involved in cell division. Centrioles exist in pairs. This pair of centrioles is shown magnified about 135 000 times.**



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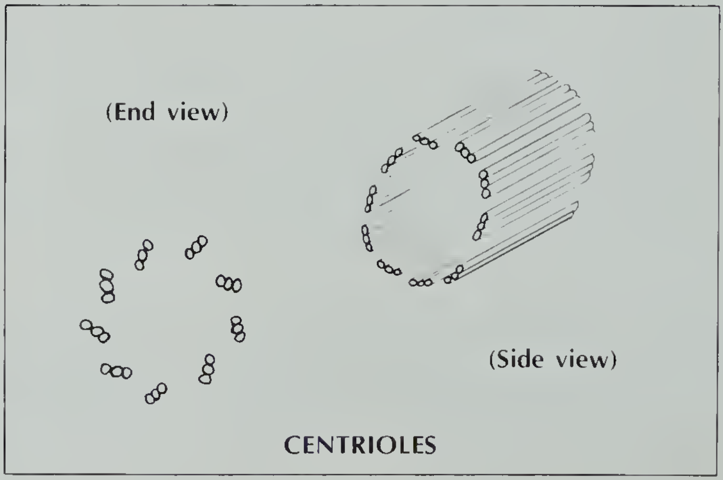

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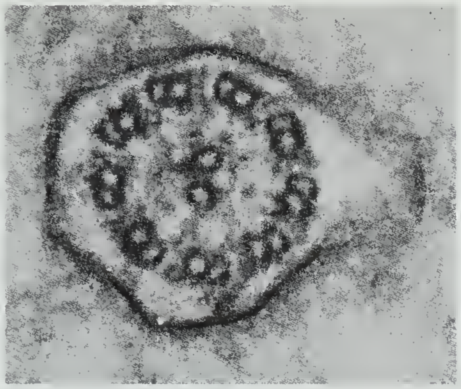

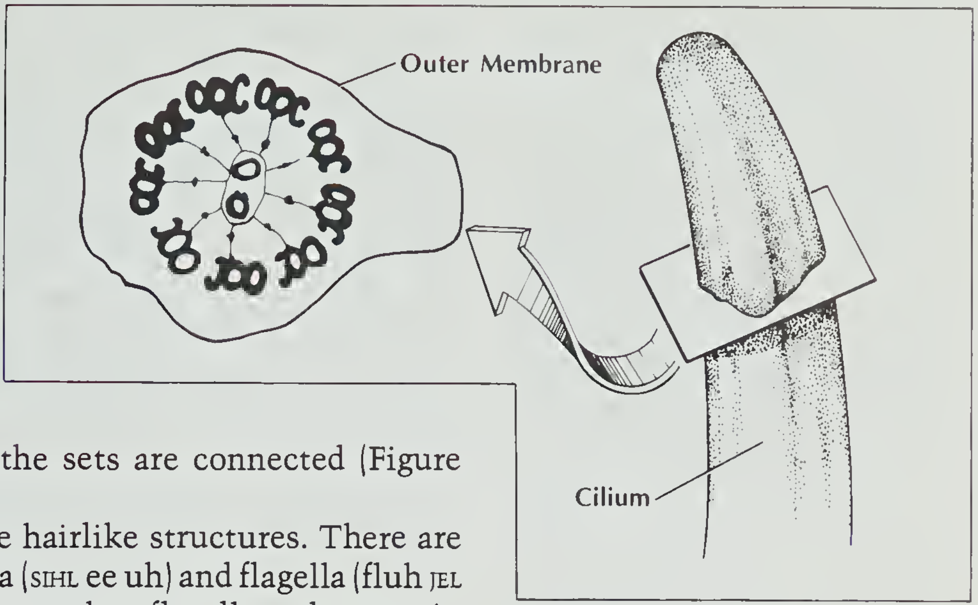

composed of three tubules and the sets are connected (Figure 5-21).

Many cells have one or more hairlike structures. There are two kinds of these structures, cilia (SIHL ee uh) and flagella (fluh JEL uh). In general, **cilia** are much shorter than flagella and appear in greater numbers. **Flagella** are longer structures and usually appear singly or in pairs. Both cilia and flagella are similar in structure to a centriole except that they have two microtubules in the center of the circle. Also, each outer set contains only two tubules. An extension of the cell membrane forms the border of cilia and flagella. Cilia and flagella are attached to the interior of a cell by a **basal body** which has the same structure. New cilia and flagella are produced from the basal bodies after cell division occurs.

Movement of cilia and flagella by unicellular organisms results in locomotion of the organism. These structures also are present on some cells of plants and animals. A sperm cell, for example, moves by means of a flagellum. Also, cells lining your windpipe have cilia. The cells do not move but the movement of the cilia helps filter the air you breathe.

**FIGURE 5-22. Cilia are movable hairlike structures that usually are smaller and exist in greater numbers than flagella. This cilium in cross section is shown magnified about 105 000 times.**

Cilia and flagella aid locomotion in unicellular organisms and some specialized cells of multicellular organisms.

**TABLE 5-1. EUKARYOTIC CELL STRUCTURES**

| Structure | Found in Cells of | Main Functions |
|---|---|---|
| CELL WALL | Plants; algae; fungi | Support; protection |
| CELL MEMBRANE | All organisms | Boundary; "gatekeeper" |
| CYTOPLASM | All organisms | Site of most metabolism |
| CENTRIOLES | Animals; some algae and fungi | Cell reproduction |
| CHLOROPLASTS | Plants; algae | Photosynthesis |
| ENDOPLASMIC RETICULUM | All organisms | Intracellular transport |
| GOLGI BODIES | All organisms | Storage; secretion |
| LYSOSOMES | Mainly animals | Intracellular digestion |
| MICROFILAMENTS | All organisms | Movement |
| MICROTUBULES | All organisms | Support; movement |
| MITOCHONDRIA | All organisms | Cellular respiration |
| NUCLEOLUS | All organisms | Production of ribosomes |
| NUCLEUS | All organisms | Control; heredity |
| RIBOSOMES | All organisms | Protein synthesis |
| VACUOLES | All organisms | Storage |

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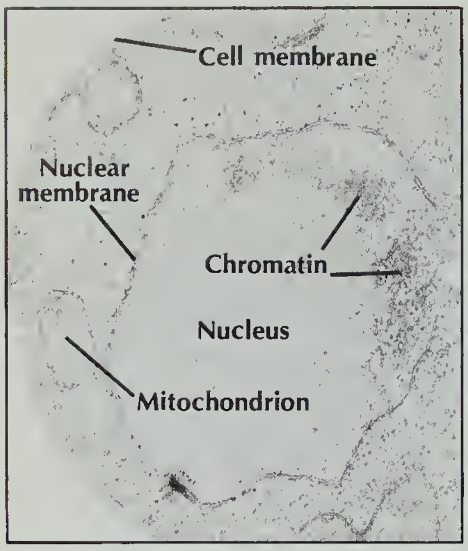


FIGURE 5-23. The nucleus is the cell's control center. It contains the cell's coded information. This cell has a large central nucleus.

## 5:15 The Nucleus

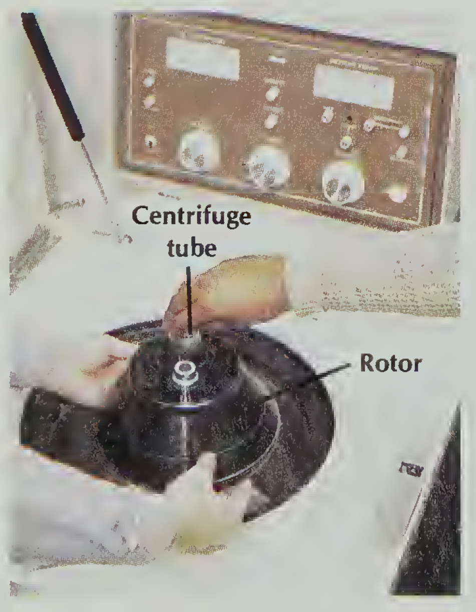
Almost every kind of eukaryotic cell contains a central, spherical body called the **nucleus.** The nucleus is the control center of the cell. It is separated from the rest of the cell by a **nuclear membrane** which is a double membrane. Definite **pores** exist in this double membrane. Certain materials may pass through these pores when they travel between nucleus and cytoplasm. Other materials move from the nucleus to the cytoplasm by way of the endoplasmic reticulum or through the membrane. Inside the nuclear membrane is nucleoplasm (Section 5:10).

Within the nucleus of most cells are one or more smaller bodies called **nucleoli** (new KLEE uh li). Nucleoli are regions that make the RNA of ribosomes. The role of the nucleus in heredity will be studied in Chapter 6.

### REVIEWING YOUR IDEAS

12. What is protoplasm? Why is it called "living stuff"?
13. What is metabolism?
14. How is division of labor in cells accomplished by cell parts? Is there division of labor in organisms other than that in cells? Explain.
15. How are prokaryotes and eukaryotes different?
16. What are the general functions of a nucleus? What separates the nucleus from the rest of the cell?

FIGURE 5-24. To separate cell parts, broken cells are put in tubes that are loaded into a special container called a rotor. The rotor is then put inside the centrifuge and spun at high speeds.



Lightforce

## ADVANCES IN BIOLOGY

## 5:16 Cell Fractionation

Microscopes can give a picture of the structure of organelles, membranes and other cell parts. The functions of the cell parts are determined by biochemical tests performed on the separated cell parts. How are the parts of a cell separated?

Separation of cell parts, **cell fractionation**, is a process that makes use of the differences in cell parts. The most important differences in the parts are size and density.

To separate cell parts, whole cells or tissues are first ground up in a blender. This step breaks down the cell membranes (and cell walls, if present) releasing the inside cell parts. The cell parts and liquid are put in a tube that is spun at high speed in an instrument called a **centrifuge**. The spinning of the centrifuge puts a downward force on the cell parts within the tube. Depending on how fast the centrifuge is run, the force can be thousands of times the force of gravity. This spinning forces larger parts to the bottom of the tube; smaller parts remain higher in the tube. Certain parts can be removed in the liquid and spinning can be repeated at various speeds to separate other cell parts by size in this way.

Sometimes cell parts that need to be separated may be the same size. Particles that are the same size can be separated by their densities. **Density** is the amount of matter that something contains in a certain volume. Nuclei, for example, are more dense than mitochondria. They contain more matter per volume. A simple and rapid separation method makes use of the buoyant (floating) properties of these cell structures.

The principle can be shown very simply using materials in your home. Cooking oil, water, and syrup are liquids of different densities. The oil is the least dense; the syrup is the most dense. If oil and syrup are in a clear glass or tube, the oil will float on top of the syrup. The formation of the two layers is chiefly the result of their different densities. If water (colored with food coloring) is poured gently over the oil, it will sink to a position between the oil and the syrup. These liquids could mix with each other, but if each is carefully layered on the next, they will form separate bands according to their densities.

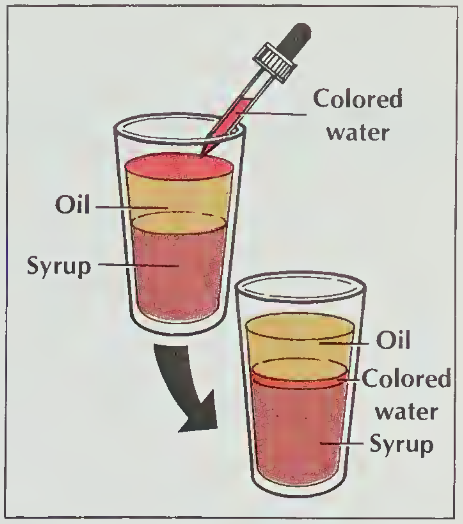


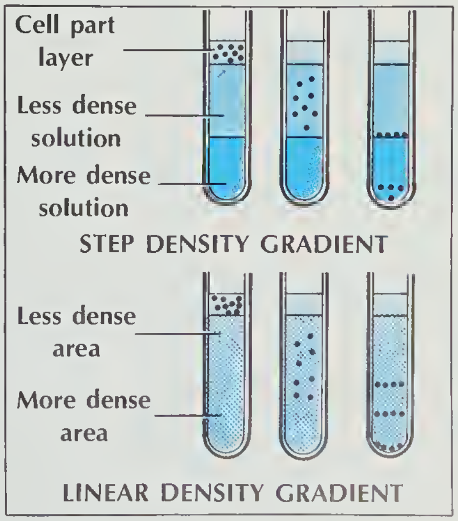
**FIGURE 5-25. Liquids of different densities will form bands as they separate.**

To separate cell parts by density, the parts are layered on top of a centrifuge tube that contains liquids of different densities in layers or steps. When the tubes are spun in the centrifuge, the cell parts move into the liquids stopping at the layer that is more dense than they are. For example, if nuclei and mitochondria are being separated, nuclei will sink to the bottom and mitochondria will float on top of the most dense layer. There are two different forces responsible for this separation. One force is gravitational force (enhanced by the spinning centrifuge) directed toward the bottom of the tube. The other force is upward buoyancy which causes the less dense cell parts to float. The spinning of the centrifuge speeds the cell part separation. Because the tube contains zones or steps of different density, the tube with the liquids is called a **step density gradient** (GRAYD ee unt).

Sometimes these methods are not adequate to separate cell parts having similar sizes and similar densities. For example, mitochondria and lysosomes differ only slightly in density and are similar in size. Another kind of gradient is used in these cases. A **linear density gradient** varies, increasing density from one end to the other, but not in discrete steps. Because each position in the tube has a different density, cell structures with different densities will end up at different positions in the tube after spinning. Each can be removed from the tube without mixing, and in this way, pure samples of cell parts can be obtained.

These techniques were developed in the 1950's and 1960's and are still vital to the study of cell parts. Once separated the cell parts can be analyzed by measuring the content of enzymes and other chemicals. Their reactions may be studied, also.

**FIGURE 5-26. Step density gradients separate particles of similar size that have different densities. Linear density gradients separate particles of similar size and similar density.**



# CHAPTER REVIEW

## SUMMARY

1. Beginning with Robert Hooke's discovery of the cell, other discoveries led to the development of the cell theory.
2. Cells can exist in many sizes and shapes and can exist independently as organisms or as parts of multicellular organisms.
3. Cells have a cell membrane which provides structure and regulates the passage of materials between the cell and its environment.
4. Water enters and leaves a cell by osmosis, a special type of diffusion. When dynamic equilibrium is reached, the number of molecules entering and leaving a cell is equal.
5. Materials can pass through a cell membrane by active or passive transport.
6. Size and solubility in fat are among the factors that influence whether particles will pass through a cell membrane.
7. Some cells obtain very large particles from their environment by endocytosis. Certain particles leave a cell by exocytosis.
8. Protoplasm is the site of much of a cell's metabolism.
9. Prokaryotes are cells that lack a definite nucleus and most of the special cell parts.
10. Specialized cell parts carry out most of the functions of eukaryotic cells.
11. Most eukaryotes have cell parts such as nuclei, mitochondria, endoplasmic reticulum, ribosomes, Golgi bodies, vacuoles, and lysosomes.
12. Cell parts not found in all eukaryotes are plastids, centrioles, cilia, and flagella.
13. The nucleus is the control center of the cell.
14. Various techniques of cell fractionation are used to separate cell parts. Once the parts are separated, their functions and other properties can be determined by biochemical methods.

## LANGUAGE OF BIOLOGY

active transport
basal body
carrier molecule
cell
cell fractionation
cell membrane
cell theory
cell wall
centrifuge
centriole
cilia
density
diffusion
endocytosis
endoplasmic reticulum
eukaryote
exocytosis
facilitated diffusion
flagella
Golgi body
grana
linear density gradient
lysosome
metabolism
microfilament
microtubule
mitochondrion
nucleus
organelle
osmosis
passive transport
phagocytosis
pinocytosis
plastid
prokaryote
protoplasm
ribosome
step density gradient
stroma
vacuole

## CHECKING YOUR IDEAS

*On a separate paper, match the phrase from the left column with the proper term from the right column. Do not write in this book.*

1. random movement of particles
2. specialization of parts
3. controls heredity
4. requires energy
5. semipermeable
6. engulfing of solid materials
7. diffusion of water
8. cell containing many organelles
9. total of cell's reactions
10. all organisms are composed of cells

a. active transport
b. cell membrane
c. cell theory
d. diffusion
e. division of labor
f. eukaryote
g. metabolism
h. nucleus
i. osmosis
j. phagocytosis

# CHAPTER REVIEW

## EVALUATING YOUR IDEAS

1. Why is the cell theory important?
2. Compare the functions of cells of unicellular and multicellular organisms.
3. How is the cell membrane important to the cell and its environment? What might happen to a cell if the membrane were permeable to all molecules?
4. Why is osmosis important to living things?
5. How does carbon dioxide travel between cells and blood?
6. How can a certain unicellular alga accumulate a concentration of potassium ions a thousand times greater than that of the surrounding water?
7. Why can passive transport be considered a "downhill" passage of materials? Why is active transport an "uphill" passage?
8. What are some factors that determine whether a particle will pass through a cell membrane?
9. Relate the structure of the cell membrane to the fact that cells differ in permeability.
10. Distinguish phagocytosis and pinocytosis.
11. Give the main functions of each of the following cell parts. Tell the kind of cell(s) in which they are usually found.
    (a) cell wall
    (b) centriole
    (c) chloroplast
    (d) cilia, flagella
    (e) ER
    (f) Golgi body
    (g) lysosome
    (h) microfilaments
    (i) microtubules
    (j) mitochondrion
    (k) nucleolus
    (l) nucleus
    (m) ribosome
    (n) vacuole
12. Why are chemicals inside a lysosome instead of being free in the cytoplasm?
13. Distinguish between rough and smooth ER.
14. Explain the means by which a substance might be produced, stored, and then secreted from a cell.
15. How are cell parts isolated for study? How are their functions determined?

## APPLYING YOUR IDEAS

1. *Paramecium* is a single-celled, freshwater organism. Its cytoplasm contains water and many other substances. What "problem" does a paramecium have? What structure might a paramecium have to deal with this problem? What might happen to a paramecium in salt water? Why?
2. Oxygen from blood continually moves into cells by diffusion. What explains that the net movement of oxygen is always much greater into the cell? (Hint: What happens to the oxygen inside the cell?)
3. Why have scientists been unable to synthesize protoplasm in the laboratory?
4. Why are there many mitochondria in a muscle cell?
5. Hormones are chemicals secreted by specialized gland cells. Name a structure which would be abundant in these cells. Explain.

## EXTENDING YOUR IDEAS

1. Prepare a report, with drawings, on five different specialized animal or plant cells.
2. Physicians often conduct a test called a basal metabolism test. What is the purpose of this test and how is it carried out?
3. Build a model of a "typical" cell. Is there really such a cell?

## SUGGESTED READINGS

Allison, A. C., *Lysosomes*, 2nd ed., Carolina Biological Reader, Burlington, NC, Carolina Biological Supply Co., 1978.

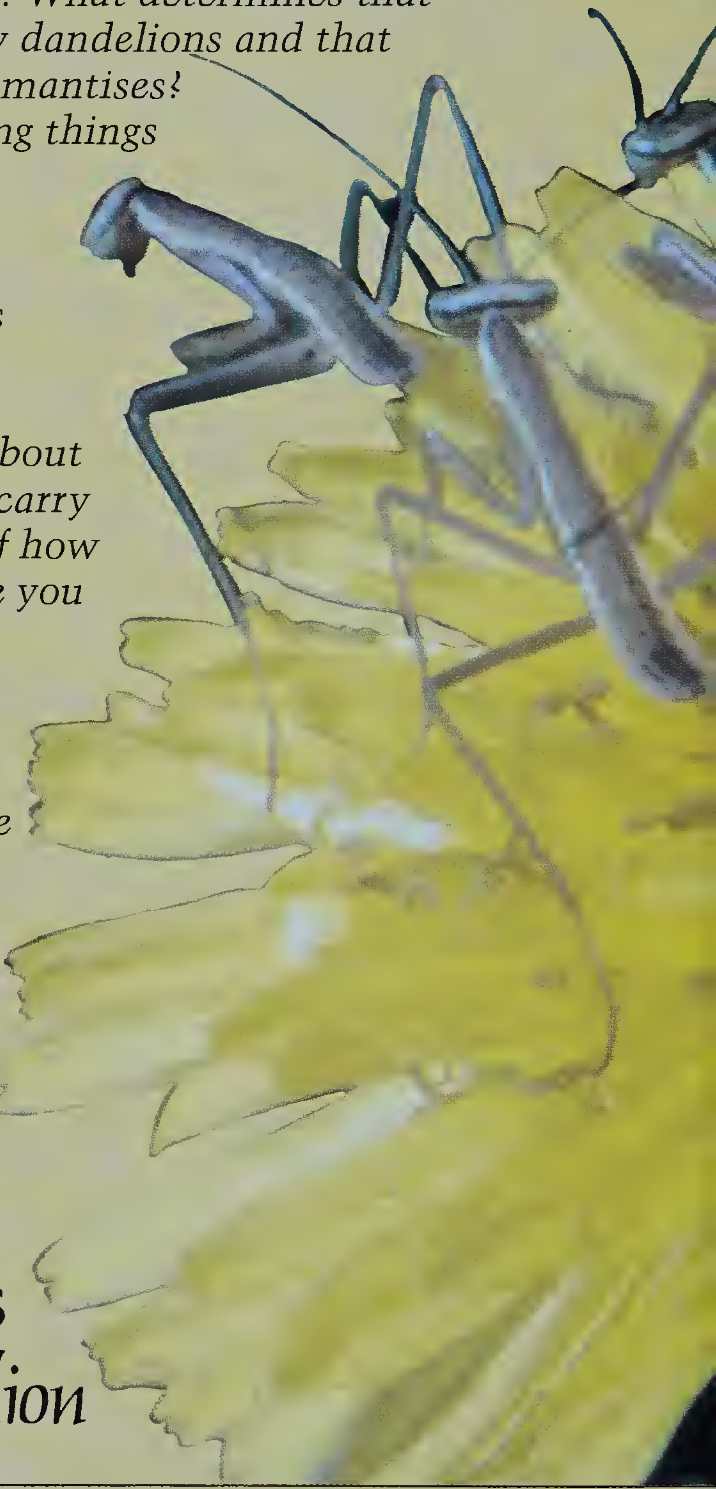
Cook, G.M.S., *The Golgi Apparatus*, 2nd ed. Carolina Biological Reader, Burlington, NC, Carolina Biological Supply Co., 1980.

Dustin, Pierre, "Microtubules." *Scientific American*, August, 1980.

# HEREDITY

*When living things reproduce, what ensures that their offspring will resemble them? What determines that dandelions will produce only dandelions and that praying mantises will produce only praying mantises? How are the features of these and other living things determined? The results of reproduction are determined by genetic messages that are copied and passed on to the offspring. The study of genetic messages and the traits that result from them is called genetics or heredity.*

*In this unit, you will learn about cell reproduction and the "vehicles" which carry genetic messages to new cells. Knowledge of how genetic information is passed on will enable you to predict some of the traits new organisms will have. You also will investigate the chemical basis of heredity. You will study the materials of which genetic messages are composed and learn how those messages are decoded to produce an organism's features.*



Praying Mantises
on Dandelion

# Unit

# II

Roger K. Burnard

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*New cells are produced by other living cells. Dividing human body cells are shown here magnified about 6400 times. The projections on the cell surfaces are extensions of the cytoplasm. How do cells divide? Are all cells produced in the same way? How do body cells differ from sperm and eggs? Are all cells produced by cell division identical to the parent cell? What are some of the ways cell division is important in your body?*

# Chapter 6

# THE CELLULAR BASIS OF HEREDITY

**GOAL:** You will gain an understanding of past beliefs concerning how living things reproduce, and present knowledge of cellular reproduction.

Aristotle (AR uhs taht uhl), 384-322 B.C., a Greek philosopher and scientist, often is called the "Father of Biology." He made important studies in anatomy and classification. Other scientists thought his reports to be true without questioning, but some of his findings and conclusions were not correct.

Long ago, many biologists thought that some living things were produced from nonliving things.

One of Aristotle's mistaken beliefs concerned the origin of organisms. He thought that some forms of life could be produced from nonliving sources. For example, Aristotle believed that eels came from the slime at the bottom of rivers or oceans. Other popular notions included the idea that maggots were produced from decaying meats and that a horse hair in water became a worm.

Lack of experimentation led to false beliefs about reproduction.

Today most people know that such beliefs are false. Why were they accepted as facts for so long? Careful observation and experimentation were not used to test these ideas. Eels were found in bodies of water and were slimy like the bottom of an ocean or river. But no one had ever studied their origin carefully. People just concluded that eels came from the slime.

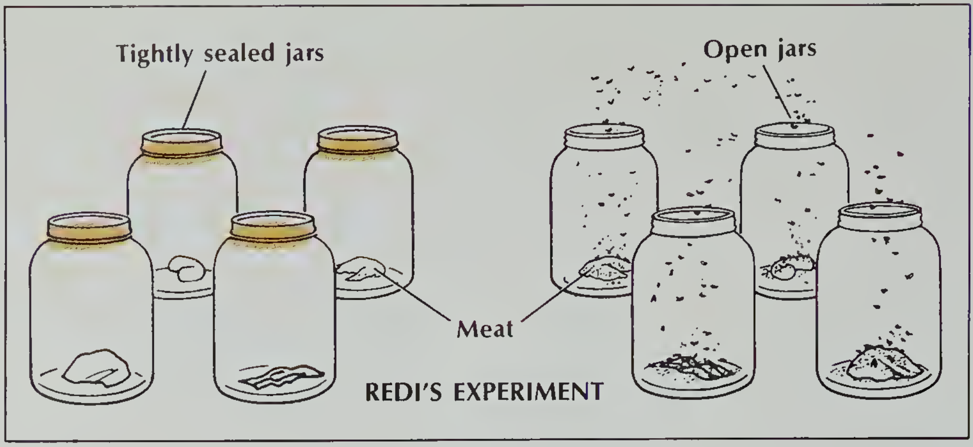
## LIFE FROM LIFE

### 6:1 Spontaneous Generation: Prologue

Spontaneous generation is the idea that living things can come from nonliving things.

The concept that living things come from nonliving things is called **spontaneous** (spahn TAY nee us) **generation.** For hundreds of years, people believed that decaying meat produced maggots.

**FIGURE 6-1.** Redi showed in a controlled experiment that maggots are not spontaneously generated from decaying meat.



Redi assumed that maggots are produced by flies.

Francesco Redi (RAY dee), an Italian physician and biologist, was not convinced that spontaneous generation occurred. Thus, he tried to show that maggots come from other living things. In 1668, he performed a series of important experiments. Redi noticed that adult flies hovered over decaying meat. He assumed that the flies produced the maggots and that if the flies could be kept away from the meat, no maggots would appear.

A controlled experiment was done to learn about the origin of maggots.

To test his hypothesis, Redi prepared eight jars with various types of meat. He left four of the jars open and sealed the other four jars. After a few days, the open jars were covered with maggots and swarming with adult flies, but the sealed jars revealed no life at all! Redi then put some maggots in a container and observed them. He noted that each maggot went through a series of changes and turned into an adult fly.

Redi's experiment did not remove all doubt about spontaneous generation.

What was the importance of Redi's investigations? By carrying out controlled experiments, Redi showed that maggots do not come from decaying meat. He did not, however, completely disprove the concept of spontaneous generation. His work was not enough to convince those who accepted the

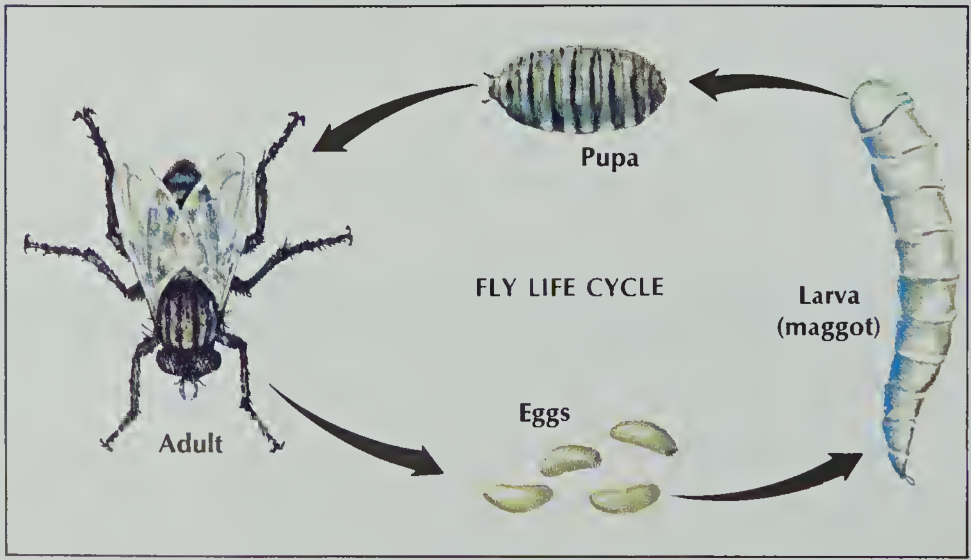


**FIGURE 6-2.** Maggots develop from fly eggs. The maggots go through a pupal stage during which they change. They emerge from the pupal stage as flies.

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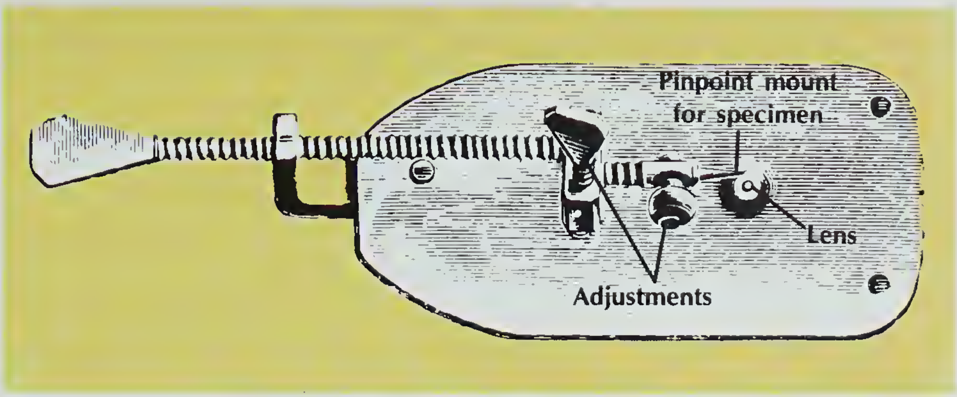


**FIGURE 6-3.** This paddlelike instrument is one of the many homemade microscopes made by Anton van Leeuwenhoek. Specimens were mounted on the pin-point and enlarged with the lens. This drawing is ⅓ larger than the actual microscope.

concept, but it began the downfall of the idea. Redi was the first to use experimental procedures to test the hypothesis. Thus, he opened the door for further investigation of the problem.

## 6:2 Convincing Evidence

Leeuwenhoek's discovery of microorganisms revived the debate about spontaneous generation.

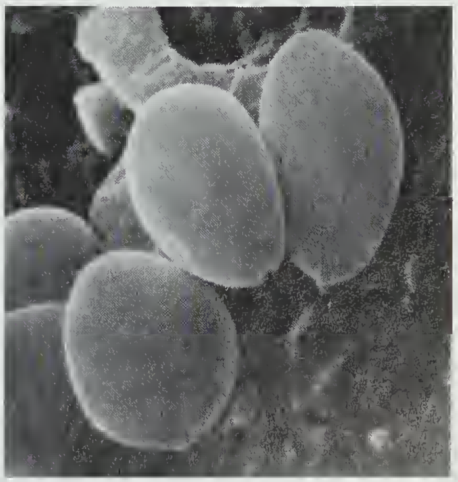
The issue of spontaneous generation of maggots and other familiar organisms gradually became settled. But, in 1675, Anton van Leeuwenhoek (LAY vun hook) discovered the world of microorganisms. A major event in itself, this discovery renewed the battle between those who believed in spontaneous generation and those who did not. These small organisms had never been seen before, so many people were quick to conclude that they were spontaneously generated.

The debate continued for almost two hundred years. Some experiments seemed to favor spontaneous generation. Others did not. Many experiments tested whether microorganisms would appear in nutrient solutions called **infusions** (ihn FYEW zhunz). Slight differences in the experiments affected the results. If air were present in the flasks containing the infusions, microorganisms usually appeared after several days. If no air were present, no life appeared. Therefore, those who believed in spontaneous generation concluded that air was an essential ingredient in spontaneous generation. They would not accept the results of their opponents' experiments.

Louis Pasteur (1822-1895), a great French scientist, opposed spontaneous generation. From earlier experiments, he believed that microorganisms came from special cells called **spores**. He thought that these small spores were carried on dust particles in the air. He believed that spores were inactive in the air but became active when materials needed for life were available (as in an infusion).

To disprove spontaneous generation, Pasteur had to keep spores from entering his infusions. Pasteur's opponents insisted that air must be present. Thus, he was faced with the problem of letting air into an infusion but keeping spores out.

**FIGURE 6-4.** These spores from a fungus are cells carried in the air. The spores are shown here magnified about 1800 times.



Dr. Judie Walton,
Lawrence Livermore National Laboratory

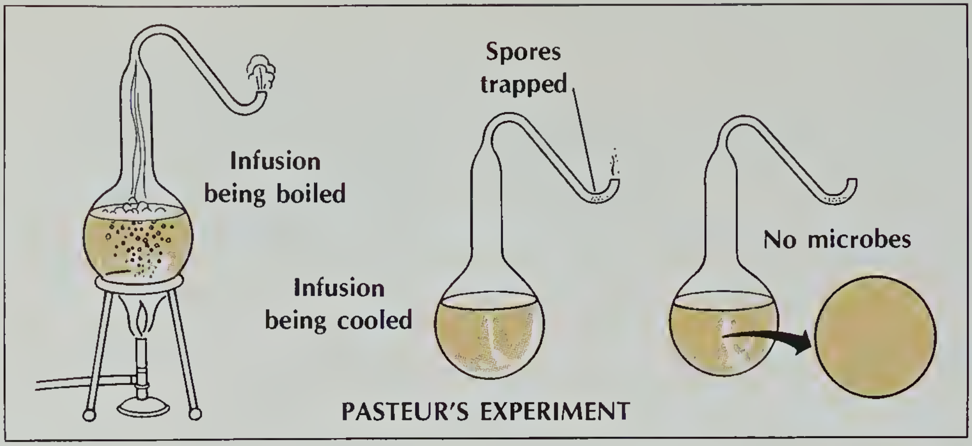


**FIGURE 6-5. Pasteur used S-shaped flasks in his experiments to disprove spontaneous generation. Although air entered the flasks, spores were trapped in the curved neck. No growth occurred in the broth.**

Pasteur devised an experiment which allowed air to enter an infusion but kept spores out.

Pasteur devised an experiment which allowed infusions to be in contact with air. He prepared infusions and boiled them thoroughly in flasks. The flasks were specially made, and had long, S-shaped necks (Figure 6-5). The boiling killed any organisms which were present in the infusion. Also, the steam produced destroyed any spores clinging to the glass. Air entering the flask would contain dust and spores, but the spores would be trapped in the curved portion of the neck. Thus the infusion would remain **sterile**, free of life, for a long time.

Pasteur's experiment showed that microorganisms, like other organisms, are produced from other living things.

Pasteur's prediction proved to be correct—the infusions remained clear. As a result, the major objection of his critics was overcome. He showed that microorganisms, like other organisms, did not come from nonliving things, and a belief held for over two thousand years was finally disproved.

The theory of biogenesis: Living things are produced only by other living things.

In this way, a principle which applied to all living things was established. Biologists refer to this idea as the **theory of biogenesis** (bi oh JEN uh sus): *at the present time and under present conditions on Earth, all living things are produced from other living things.*

The cell theory and the theory of biogenesis fit together.

Pasteur's convincing evidence about the reproduction of living things appeared in 1864. Recall that the announcement came in 1858 that all cells come from other cells (Section 5:1). These two discoveries were each important as biological principles, but more important, they fit together. Cells are the basic units of structure and function, and all cells are reproduced from other cells. Thus, all life must come from living things.

## REVIEWING YOUR IDEAS

1. Why was the idea of spontaneous generation believed for a long time?
2. Why did Redi seal only some of the jars in his test? Why did he observe fly development?
3. Why did Pasteur use a flask with an S-shaped neck?
4. State the theory of biogenesis.

# REPRODUCTION OF CELLS

## 6:3 Importance of the Nucleus

Facts being gathered about cells led biologists to believe that the cell is the basis of heredity. They correctly assumed that a study of cell reproduction would lead them to a better understanding of reproduction in general. The discovery of special dyes and stains aided microscopic study of cell division. Viewing of living cells became easier as better microscopes were made.

It soon was evident that the nucleus has a major role during cell reproduction. Almost every kind of eukaryotic cell contains a **nucleus** (Section 5:15). The nucleus is the control center of the cell. Prokaryotic cells, although they do not have nuclei, do have nuclear material.

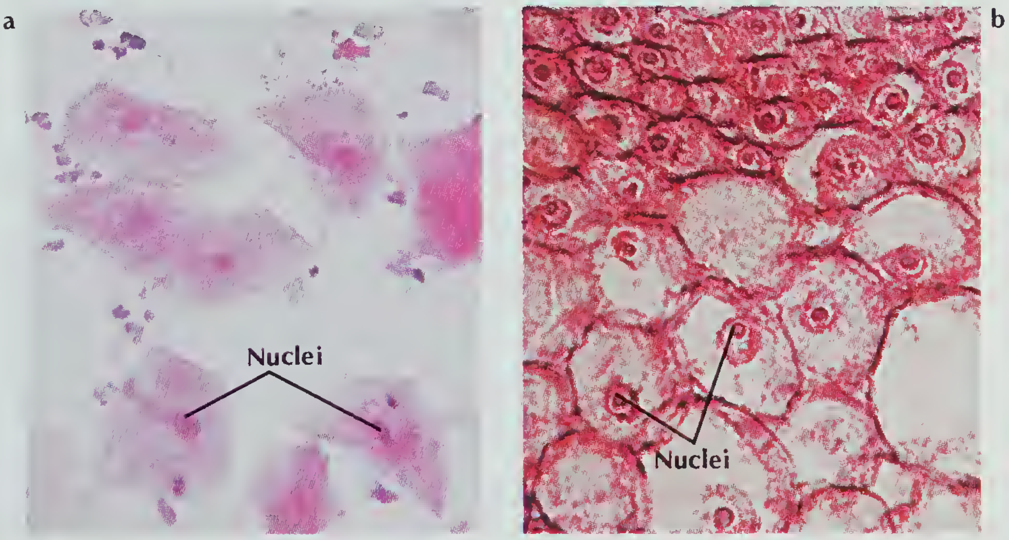
The nucleus is the control center of eukaryotic cells.

The main substance located in the nucleus is called **chromatin** (KROH mut un). Although chromatin structure has been studied for many years, it is still a current area of biochemical research. Chromatin appears as a mass of material. However, during cell division, chromatin appears as distinct bodies called **chromosomes** (KROH muh sohmz). Chromosomes are composed of **nucleoprotein** (new klee oh PROH teen), a combination of nucleic acid (DNA) and protein. DNA is the material which carries the "genetic code." Therefore the nucleus is important in heredity.

When cells reproduce, chromatin can be seen as distinct chromosomes.

Each time a cell divides, the chromosomes must be replicated and the copies must be distributed to each new cell. A process in eukaryotes in which chromosomes are replicated and distributed to new nuclei is called **mitosis** (mi TOH sus). Nuclear replication and division and cytoplasm division often occur at the same time. However, mitosis refers only to the replication and division of the nuclear material.

Mitosis involves the replication of chromosomes and their equal distribution to new nuclei.



Tom Stack and Associates

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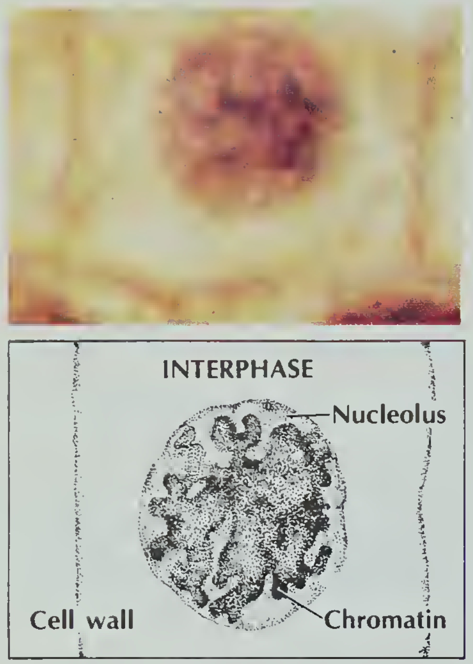
**FIGURE 6-6. (a) These animal cells and (b) plant cells show cell nuclei clearly. The main substance in a cell nucleus is chromatin.**



Roger K. Burnard

**FIGURE 6-7. Although they appear inactive, interphase cells are actively taking in and making materials. Chromosomes are not distinct in interphase but are undergoing duplication.**

## 6:4 Interphase

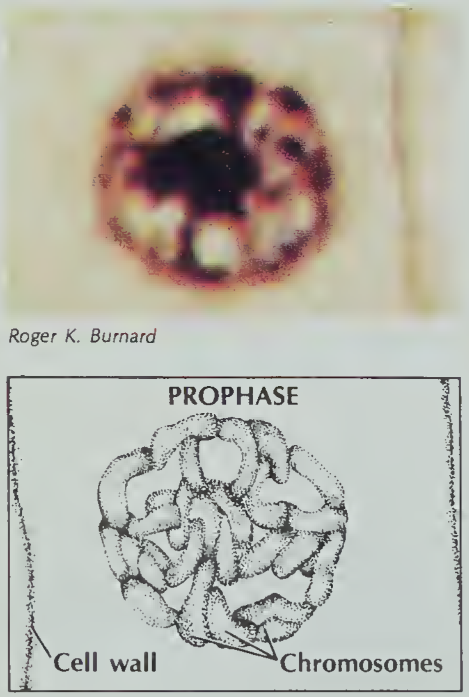
For most of its life, a cell appears to be in a state of little activity. This part of a cell's life cycle, called **interphase** (IHNT ur fayz), is the state before and after mitosis. When you observe living cells through a microscope, you most often see them in interphase.

During interphase, a cell nucleus is composed mainly of the membrane, a nucleolus or nucleoli, and chromatin. During interphase, the chromatin is long, thin, and intertwined and is not seen as distinct bodies. During cell division, the chromatin condenses into distinct chromosomes. It is thought that chromosomes are one or a few thin "threads" containing DNA, the material which carries the genetic message.

Although interphase cells appear to be inactive, they are active in receiving and making materials needed for growth, development, and maintenance. Also, they are making the substances needed for cell division.

Chemical tests show that *each chromosome replicates before mitosis begins*. The significance of this replication is great because chromosomes are the code carriers for proper cell functioning. Each new cell must have a complete and accurate copy of the code. Mitosis achieves this accurate copying and dividing of genetic information. When the cell divides, the new cells each get a complete copy of the code.

**FIGURE 6-8. In prophase, the nuclear membrane disappears and chromosomes become visible.**



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## 6:5 Mitosis

Although cell division is a continuous series of events, there are four main phases of mitosis. The four phases are **prophase** (PROH fayz), **metaphase** (MET uh fayz), **anaphase** (AN uh fayz), and **telophase** (TEL uh fayz). Each phase can be thought of as frames of a movie.

- **Prophase**. Prophase is a series of events which sets the stage for later events. Those events lead to the equal distribution of chromosomes to new nuclei. Prophase follows interphase. In early prophase, the nucleolus (or nucleoli) begins to disintegrate. Chromatin becomes thicker and shorter, but separate chromosomes are not clearly seen. By middle prophase, the nucleolus has disappeared completely. Chromosomes are clearly visible, and the nuclear membrane begins to break down. In animal cells, centrioles (Section 5:14) begin to separate and migrate toward opposite poles of the cell. Microtubules (Section 5:12) then form as tiny fibers between the poles.

By late prophase, the nuclear membrane is completely absent. Chromosomes appear even more distinct and can be seen to be replicated. They appear as double-stranded structures. Each strand is called a **chromatid** (KROH muh tud). The chromatids of a chromosome are joined at a special region, the **centromeres** (SEN truh mihrz). Microtubules form an oval-shaped structure between the poles of the cell called the **spindle**. Other fibers, the **aster**, radiate outward from the centrioles in most animal cells. Most other eukaryotic cells lack centrioles and asters, but they do have spindles.

- **Metaphase**. During metaphase, a short stage, chromosomes move toward the center of the cell. The centromeres of each chromosome (2 chromatids) attach to a separate spindle fiber. They are attached near the center or "equator" of the cell. The rest of the chromatids may face in any direction.
- **Anaphase**. Separation of chromatids marks the onset of this stage. A chromatid of each pair is pulled to each pole of the cell. How the chromosomes move is not fully understood. The pull may occur as the microtubules break down and the fibers shorten.

At the end of anaphase, there is one set of single-stranded chromosomes at each end of the cell. The cell membrane of animal cells begins to pinch together at the cell's center. Microfilaments (Section 5:12) seem to be involved. In plants, the **cell plate** begins to appear midway across the cell. The cell plate may form from membranes of Golgi bodies or ER. The cell plate will become the membranes of the two new cells. Later new cell walls form between the membranes.

*Ward's Natural Science Establishment, Inc.*

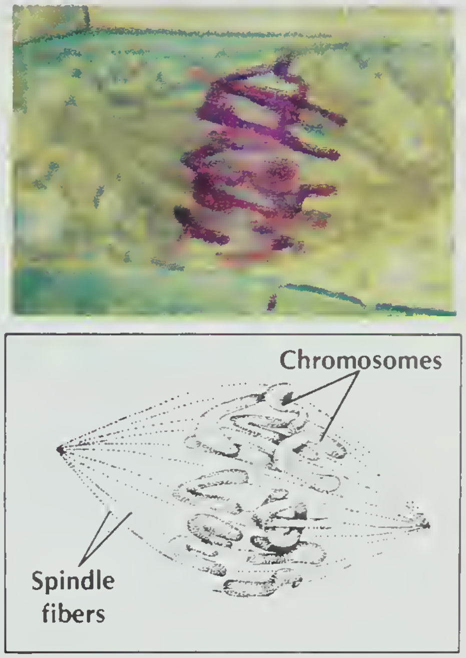


**FIGURE 6-9.** A spindle is an oval-shaped structure made of microtubules. Chromosomes attach to the spindle fibers.

By the end of anaphase, one set of single-stranded chromosomes has been pulled to each end of the cell.

*Roger K. Burnard* *Roger K. Burnard*

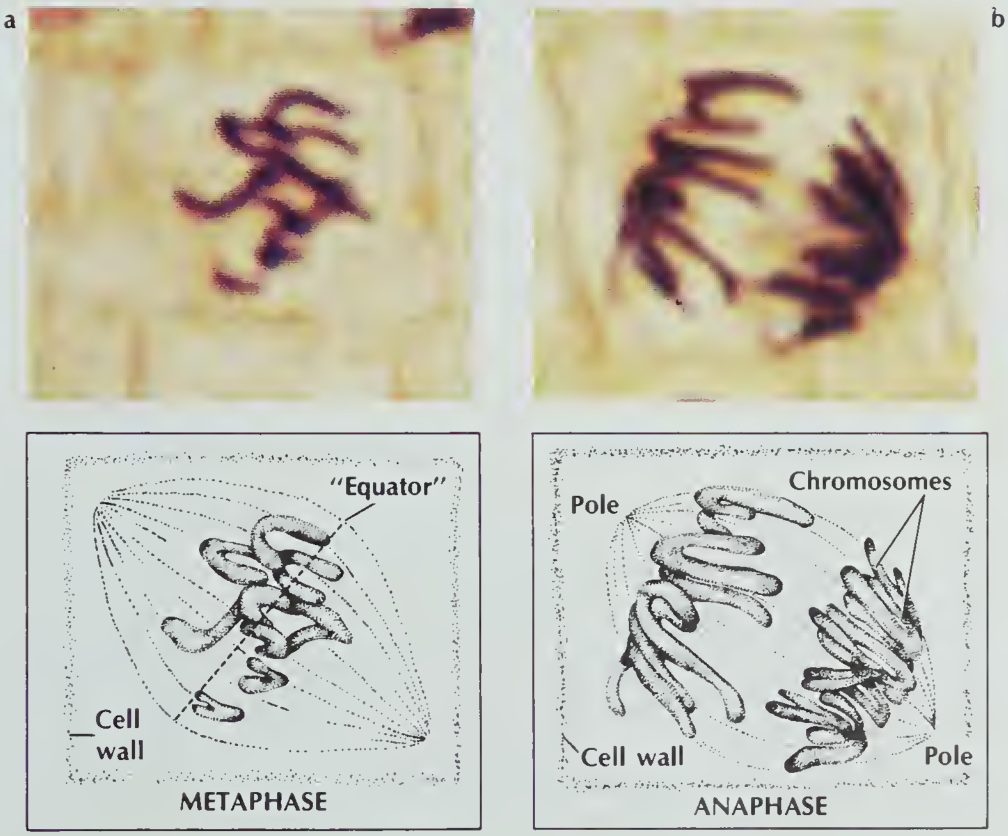


**FIGURE 6-10.** (a) During metaphase, chromosomes line up at the center ("equator") of the cell. (b) During anaphase, chromatids of each chromosome separate and begin moving to opposite ends (poles) of the cell.

- **Telophase**. Telophase ends mitosis with events opposite to those of prophase. The nucleolus reappears, and a nuclear membrane forms around each set of chromosomes. The nuclear membrane forms from ER. Meanwhile, chromosomes lose their distinct form so they once again appear as a mass of chromatin. In animal cells, when cell division is completed, the cell membrane pinches completely together so that the single cell is separated into two **daughter cells**. In plants, the cell plate is completed to form the daughter cells. Eventually cell walls will form between the plant cells. In late telophase of animal cells, the centrioles also replicate.

Each daughter cell has the same number and kinds of chromosomes as the parent cell which produced it. After mitosis, the daughter cells enter interphase. As they mature and grow, their single-stranded chromosomes eventually will be replicated. Then, mitosis can begin again.

*Roger K. Burnard*

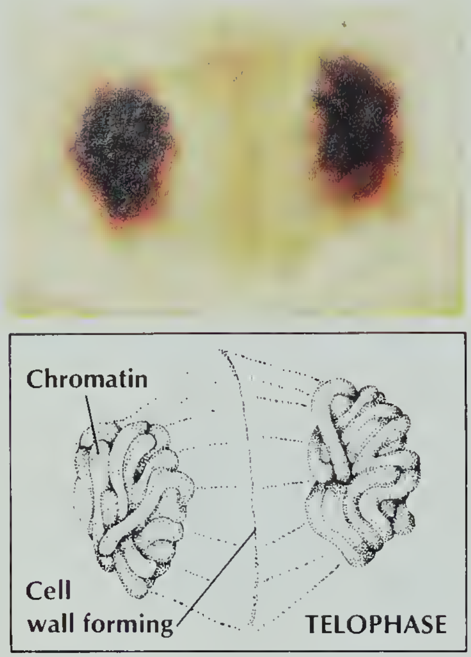

Chromatin
Cell wall forming
TELOPHASE

**FIGURE 6-11. During telophase, chromosomes finish moving to opposite poles of the cell and the formation of two daughter cells occurs.**

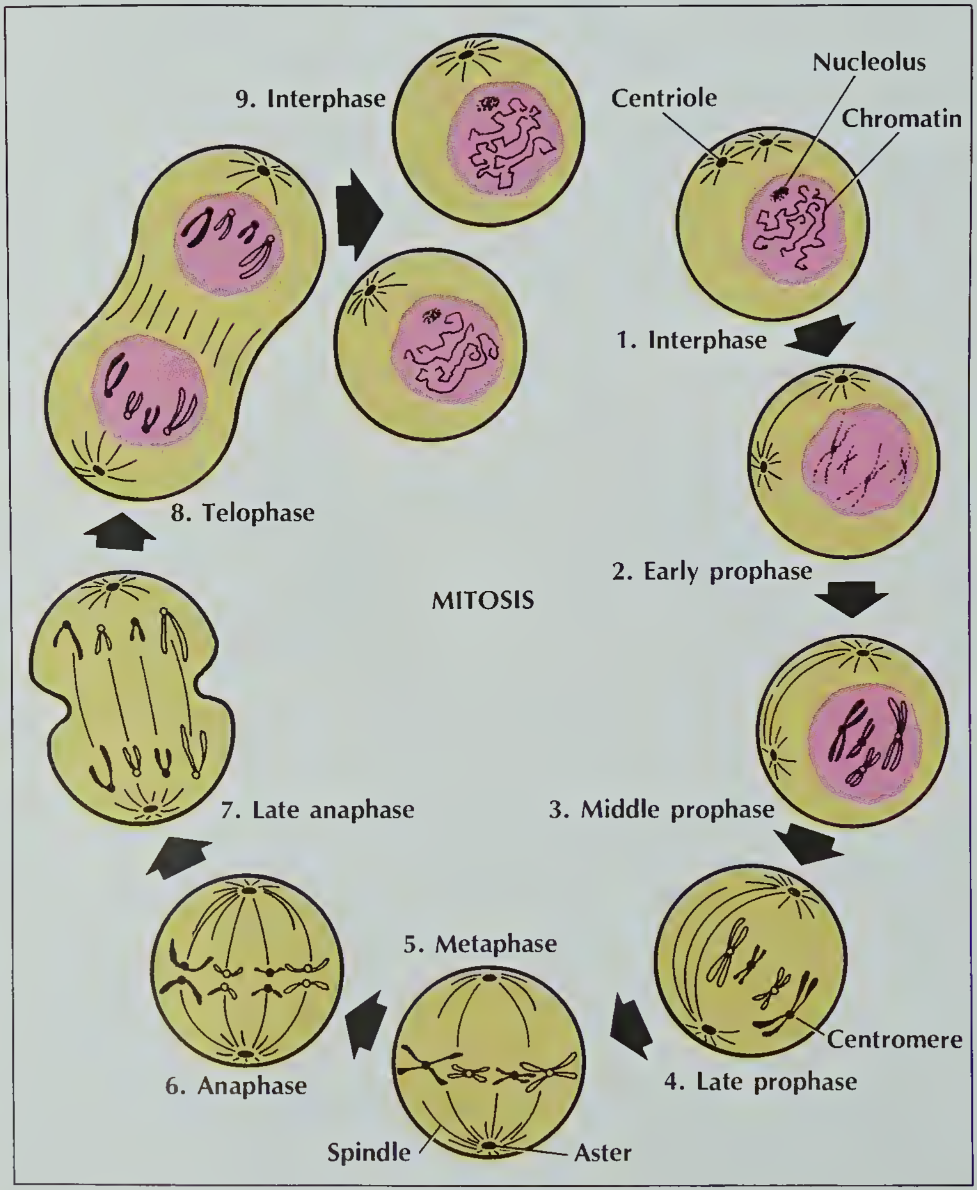
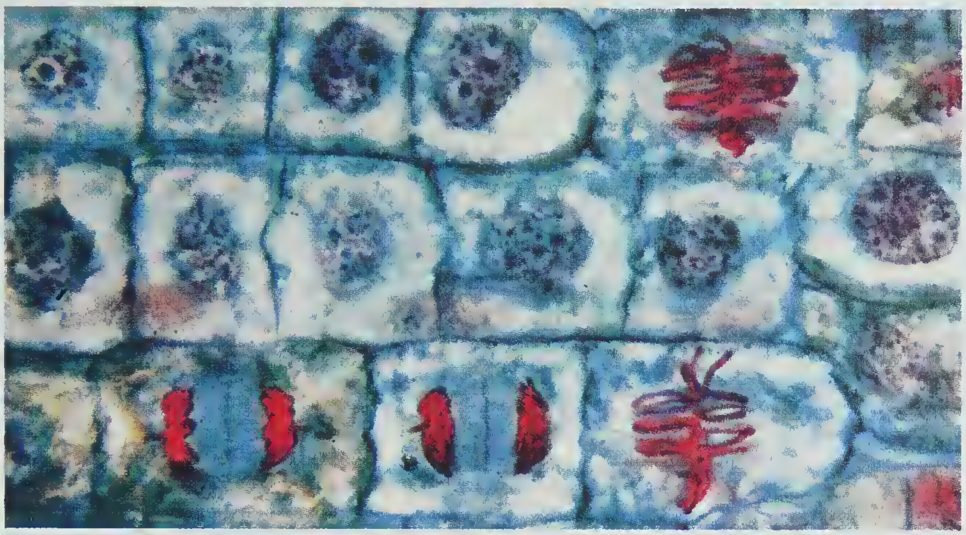

MITOSIS
Nucleolus
Centriole
Chromatin
1. Interphase
2. Early prophase
3. Middle prophase
Centromere
4. Late prophase
5. Metaphase
Spindle
Aster
6. Anaphase
7. Late anaphase
8. Telophase
9. Interphase

FIGURE 6-12. Mitosis ensures that each daughter cell has the same number and kinds of chromosomes as the parent cell. Follow the movement of the chromosomes through the stages of mitosis.



Courtesy CCM: General Biological, Inc.

**FIGURE 6-13. Stained cells from an onion root tip show different stages of mitosis. Which stages can you identify?**

## 6:6 Analysis of Mitosis

Mitosis is a process which guarantees genetic continuity (kahnt un EW ut ee) when it occurs properly. **Genetic continuity** results in the reproduction of offspring with the same set of features as the parent.

Mitosis guarantees genetic continuity.

Normally, a cell has one of each kind of chromosome during most of the cell's life. However, during interphase, each chromosome is replicated. Replication is necessary in order to give the same genetic message to each new cell. If exact replication fails to occur, the daughter cells will not receive the genetic message correctly. In this case, they probably would function improperly, or they might die.

Replication of chromosomes during interphase is essential.

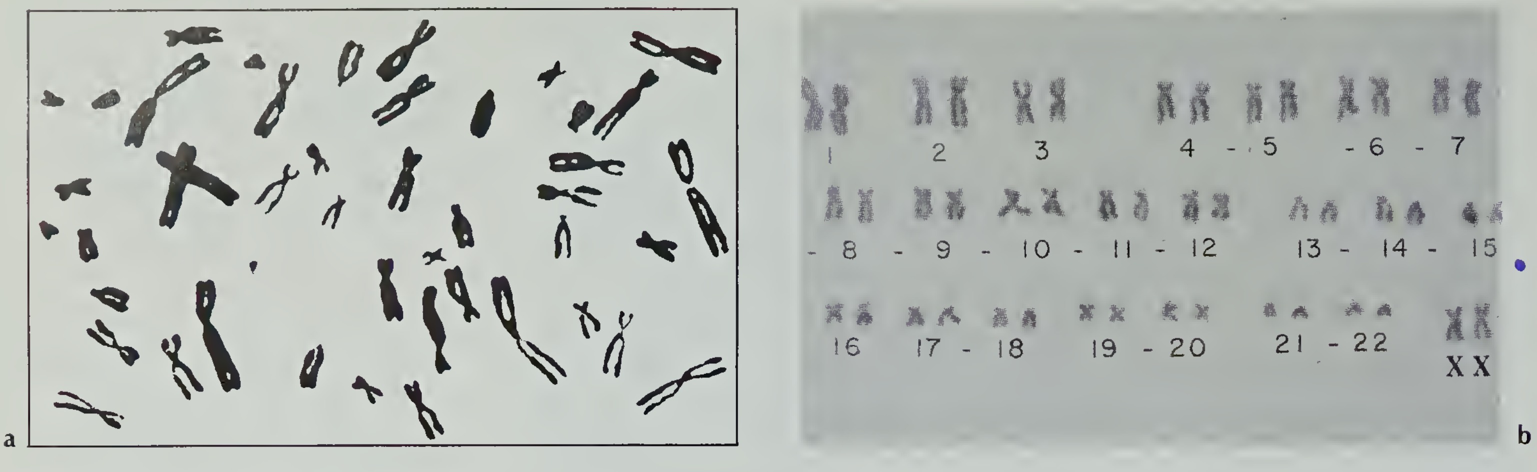
Once the genetic message is replicated, exact separation of chromosomes also is necessary. During metaphase, each chromosome lines up on a *separate* spindle fiber. Thus, after separation, *one of each kind of chromosome* will be present in each new nucleus. What would happen if the chromosomes were to line up in a random fashion?

Because of how chromosomes line up at metaphase, each daughter cell has one of each kind of chromosome.

## 6:7 Chromosome Number

The number of chromosomes per cell varies from one kind of organism to another. Humans have forty-six chromosomes per cell and fruit flies have eight. The cell in Figure 6-12 has a total of four chromosomes. Some types of organisms have several hundred chromosomes per cell. Each cell of each kind of organism has a certain number of chromosomes, and each cell of an organism should have the same number and kinds of chromosomes. Also, a certain chromosome from one cell carries the same kind of information as its counterpart in another cell.

Each kind of organism has a specific number of chromosomes per cell.



Thomas Russell

**FIGURE 6-14.** (a) Chromosomes can be photographed and then (b) paired in a karyotype. This karyotype shows the chromosomes of a normal human female. Humans have 23 pairs of chromosomes.

The monoploid number is the number of different pairs of chromosomes per cell *(n)*.

The diploid number is the total number of chromosomes per cell (2*n*).

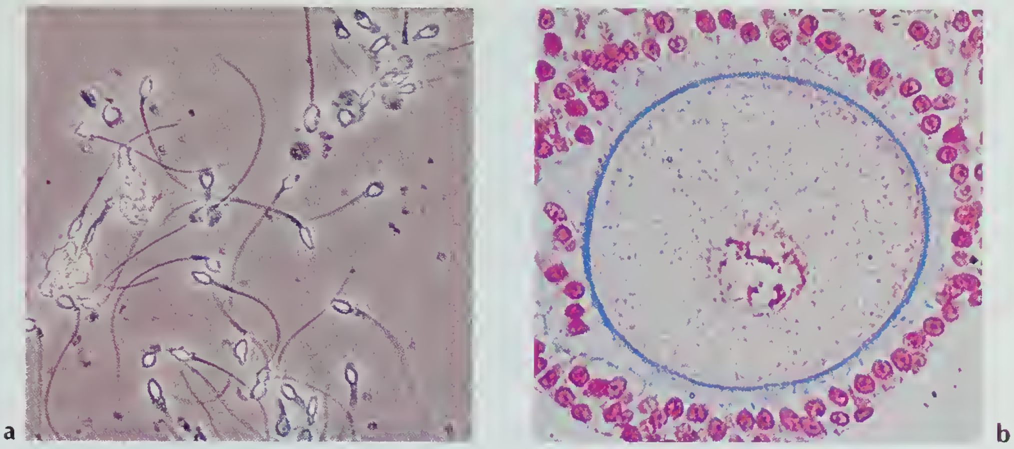
The two chromosomes of each pair are called homologs.

Chromosomes can be isolated and separated for detailed study of features. All of the features of the chromosomes, including size and number, make up a cell's **karyotype** (KER ee uh tipe). Karyotypes show that each cell of a certain kind of organism does have the same number and kinds of chromosomes and that *chromosomes of many organisms exist in pairs.* In humans there are twenty-three pairs, and in fruit flies there are four pairs per cell. The number of different pairs is given as $n$, which is the **monoploid** (MAHN uh ployd) **number** of chromosomes. In humans, $n = 23$. The total number of chromosomes per cell is $2n$ which is called the **diploid** (DIHP loyd) **number.** In humans, $2n = 46$. What are $n$ and $2n$ in fruit flies?

Each partner in a pair of chromosomes has the same basic shape and structure. The two chromosomes of each pair are said to be **homologous** (huh MAHL uh gus), and they are referred to as **homologs** (HOH muh lawgz). Each homolog carries information for the same hereditary trait as its partner, but the specific instructions may differ. For example, each homolog of a pair may carry a coded message for eye color. One chromosome's message may be for brown eyes, and the other chromosome's message may be for blue eyes. The combination of the two sets of instructions determines the result in the offspring. A single pair of homologs may carry information for several thousand hereditary traits.

## REVIEWING YOUR IDEAS

5. What is mitosis? Where does it occur?
6. Distinguish between chromatin and chromosomes. Of what important chemical are they mainly composed?
7. What happens during interphase just before mitosis begins?
8. Describe the appearance of a chromosome early in mitosis.
9. Distinguish between a spindle and an aster.
10. What is the result of mitosis and cell division?
11. What does a karyotype show?



Manfred Kage for Peter Arnold

Manfred Kage for Peter Arnold

**FIGURE 6-15.** The products of meiosis are (a) sperm cells and (b) egg cells. (Only one egg cell is shown here.) A sperm and an egg each carry half the genetic message.

## 6:8 Meiosis

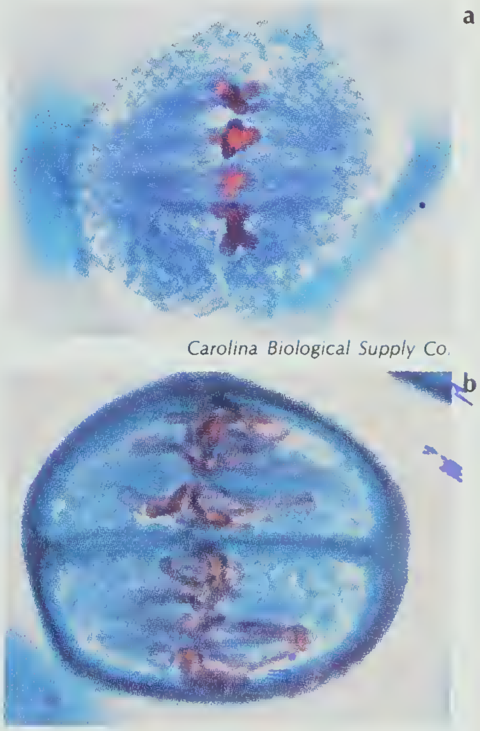
What is the source of the two homologs of each pair of chromosomes in each cell? Development usually starts with a fertilized egg or **zygote** (ZI goht). Genetic information in the zygote guides development as mitosis produces a new multicellular organism. The zygote results from the union of two different kinds of cells, the sex cells. The sex cells, also called **gametes** (GAM eets), are a **sperm** from the male parent and an **egg,** or **ovum** (OH vum), from the female parent. Each sperm and egg contains only one member of each pair of chromosomes. Thus, one half of the diploid number in the zygote is from the male parent, and the other half is from the female parent.

Gametes, eggs and sperm, contain only one member of each pair of chromosomes.

Each sperm and egg cell contains only half the diploid number of chromosomes. Because mitosis yields daughter cells with the diploid number of chromosomes, production of sperm and eggs must involve a different process. Also, not just any half of the chromosomes will do because each sperm and egg must contain the *monoploid* number of chromosomes. Each sex cell must have *one member of each homologous pair.* The process by which the gametes are produced is called **meiosis** (mi OH sus). Correct meiosis ensures that the sex cells will have the right *number* and *kinds* of chromosomes. As a result, the zygote gets the proper *number* and *kinds* of chromosomes when fertilization occurs.

Meiosis occurs in certain tissues of an animal's reproductive organs and produces gametes. Meiosis also occurs in the life cycles of plants, algae, fungi, and some unicellular organisms. In plants and some algae and fungi, meiosis results in special cells called spores. Meiosis in unicellular organisms often produces monoploid nuclei rather than special cells. In any case, meiosis occurs in two major parts—**meiosis I** and **meiosis II**. Each stage of meiosis is labeled with a Roman numeral I or II.

**FIGURE 6-16.** (a) In meiosis I, the members of each pair of chromosomes separate and move apart forming two cells. Chromosome pairs are shown lined up at the center of the cell. (b) In meiosis II, chromosomes line up at the center of each cell and the chromatids separate. Four cells result, each with half the chromosome number of the original cell.



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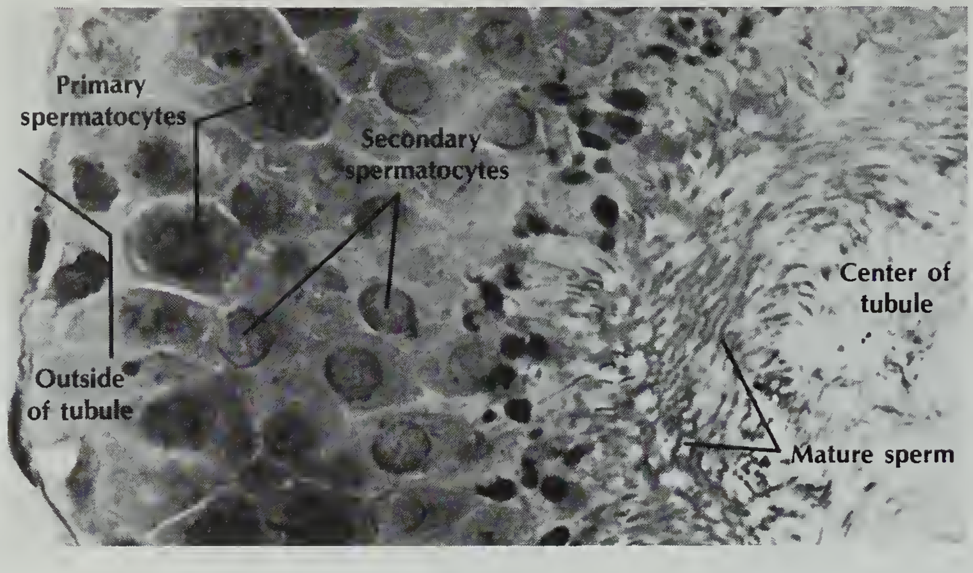


**FIGURE 6-17. Meiosis in males occurs in tubules in the testes. Part of one of the tubules is shown magnified about 1800 times. Cells near the outside of the tubule (left) move toward the tubule's center (right) as they undergo meiosis. The dark lines at the right are mature sperm.**

## 6:9 Meiosis in Males

Chromosomes replicate prior to meiosis I.

During prophase I, homologous chromosomes move close together.

The main events of meiosis as it occurs in a male animal are diagrammed in Figure 6-18. In early prophase of meiosis I, chromosomes do not appear to be double-stranded. However, studies show that the chromosomes are replicated during interphase (as in mitosis). In middle prophase I of meiosis, homologous chromosomes move close together by a process called **synapsis** (suh NAP sus). Not only do the chromosomes come together, but identical parts lie side by side. During this time the chromosomes may be wound around one another. Finally, in late prophase I, the replicated chromosomes are seen clearly. The cell now is called a **primary spermatocyte** (spur MAT uh site). Each pair of chromosomes is called a **tetrad** (TEH trad) because four strands (chromatids) lie close together.

While these chromosome activities are occurring, the cell undergoes some events similar to mitosis. The nucleolus (if present) and nuclear membrane disappear, the centrioles move apart, and the spindle and aster form. The major difference between this prophase and prophase of mitosis is that the homologous chromosomes are paired in meiosis I.

In metaphase I, tetrads attach to spindle fibers.

During anaphase I, one double-stranded chromosome of each tetrad is pulled to each pole.

There is another main difference in mitosis and meiosis that occurs in metaphase I. Each chromosome does not attach to a separate spindle fiber in meiosis. Instead, each *tetrad*, or pair of chromosomes, attaches to a separate fiber. During anaphase I which follows, the spindle fibers contract, and *one pair of chromatids of each tetrad is pulled to each pole.*

In males, meiosis I produces two secondary spermatocytes, each of which is monoploid.

Then, the cell membrane begins to pinch in and telophase I begins. The original cell is divided to form two **secondary spermatocytes** in which each cell has one member of each homologous pair ($n$). However, the chromosomes consist of two chromatids still joined together.

Meiosis II usually follows right after meiosis I. Meiosis II is much like mitosis. The secondary spermatocytes may skip prophase and go into metaphase directly (Figure 6-18).

Meiosis II is like mitosis.

**TABLE 6-1. COMPARISON OF MITOSIS AND MEIOSIS**

| | Mitosis | Meiosis |
|---|---|---|
| Occurs in | all body cells | certain cells of reproductive organs |
| Number of cells produced | two | four (3 may die) |
| Chromosome number of parent cell | diploid (2n) | diploid (2n) |
| Chromosome number of daughter cells | same as parent cell | monoploid (n) |
| Kind of cells produced | various body cells | gametes or certain spores |
| Function | genetic continuity from cell to cell | genetic continuity between generations; promotes variation |

A total of four monoploid cells, called **spermatids,** are produced by meiosis II. A flagellum (Section 5:14) then forms from one of the centrioles of each spermatid. The spermatid with the tail becomes a sperm. The flagellum helps the sperm swim toward an egg aiding fertilization.

In males, four spermatids are produced from one primary spermatocyte.

## 6:10 Meiosis in Females

Production of eggs by meiosis in a female animal follows the same general pattern as sperm production, but there are interesting differences. Meiosis I in human females begins before birth! As early as the third month of development, **primary oocytes** (OH uh sites) begin to form in a female fetus. (Oocytes correspond to the spermatocytes of males.) Meiosis is stopped at this point until sexual maturity is reached many years later. At this point, on a cyclic basis, several primary oocytes continue meiosis I, but usually only one per cycle survives. A primary oocyte divides to produce two cells of unequal size. The larger cell is the **secondary oocyte,** and the smaller cell is the **first polar body.** The first polar body may divide again, but cells produced from the first polar body do not survive.

In females, meiosis I begins before birth.

A fetus is a developing organism.

Unequal cell division of a primary oocyte produces a secondary oocyte and the first polar body.

The secondary oocyte enters meiosis II and divides unequally to form a small **second polar body** and a large **ootid** (OH uh tihd). The polar body dies, but the ootid develops into a mature ovum (Figure 6-18).

An ootid develops into a mature egg.

Another difference in the making of the sperm and the egg is that the sperm must be in its final form before fertilization can occur. Oocytes can be fertilized before they are mature.

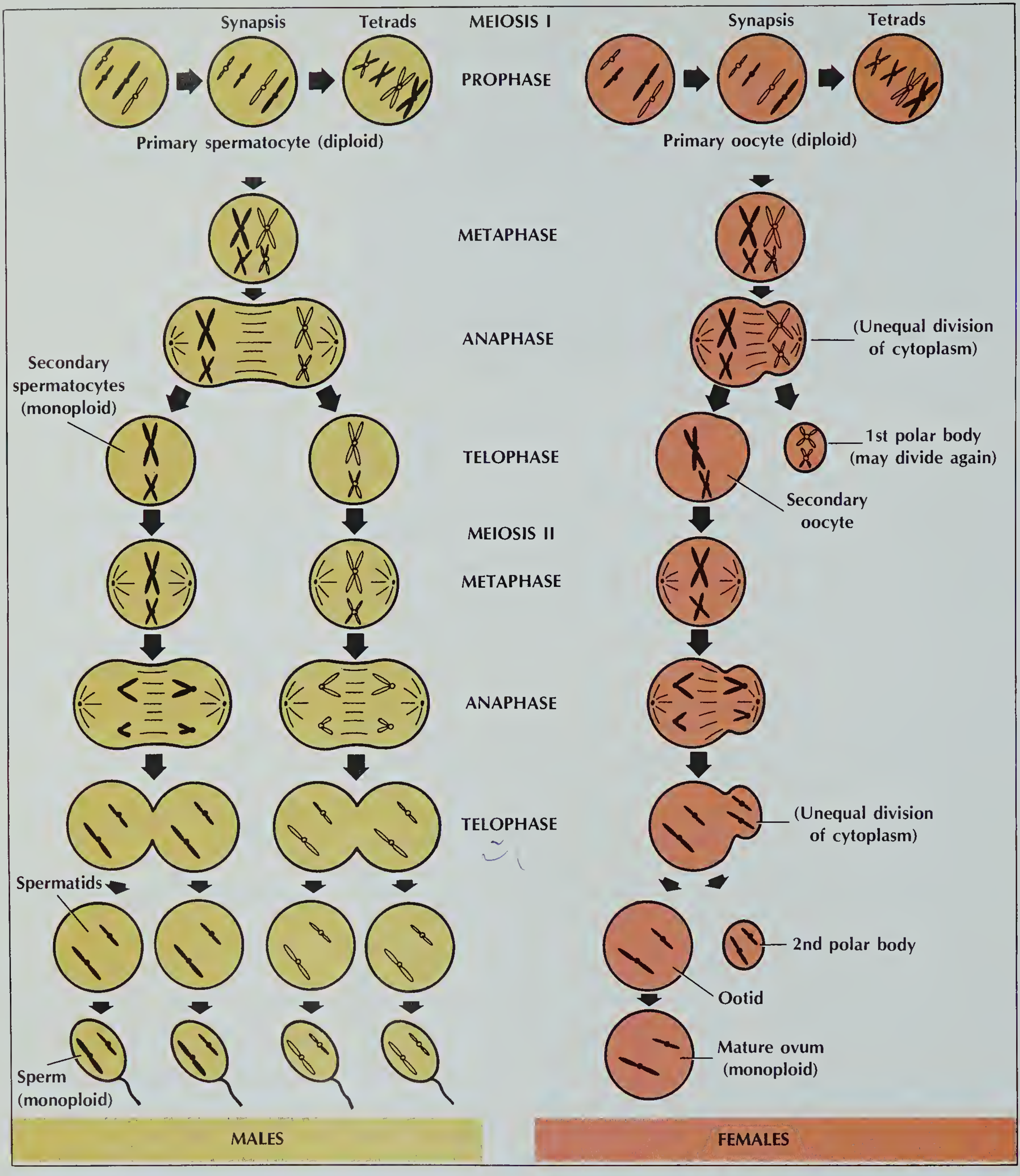

Synapsis
Tetrads
MEIOSIS I
Synapsis
Tetrads
PROPHASE
Primary spermatocyte (diploid)
Primary oocyte (diploid)
METAPHASE
ANAPHASE
(Unequal division of cytoplasm)
Secondary spermatocytes (monoploid)
TELOPHASE
1st polar body (may divide again)
Secondary oocyte
MEIOSIS II
METAPHASE
ANAPHASE
TELOPHASE
(Unequal division of cytoplasm)
Spermatids
2nd polar body
Ootid
Mature ovum (monoploid)
Sperm (monoploid)
MALES
FEMALES

FIGURE 6-18. Meiosis yields cells with half the number of chromosomes as the parent cell. Compare and contrast meiosis in males with meiosis in females.

In a male, four sperm cells develop from each cell (primary spermatocyte) that undergoes meiosis. But, only one egg develops from each cell (primary oocyte) that undergoes meiosis in a female. Can you think of any way in which unequal cell division in a female is adaptive?

## 6:11 Importance of Meiosis

Meiosis assures that the genetic code is passed from one generation to the next.

Meiosis assures that the genetic code of a certain kind of organism is passed to the next generation. This special means of reaching the monoploid number of chromosomes is necessary. If it did not occur, the next generation could not exist in the same form as its parents. Perhaps it could not exist at all.

Meiosis and fertilization contribute to variety among offspring.

Meiosis provides more than the continuing of the genetic code. Most organisms have some means of sexual reproduction. Meiosis and fertilization needed for sexual reproduction also provide the means for variation among offspring. Meiosis and fertilization have a special advantage for organisms. Reproduction by mitosis alone produces little variety in offspring.

In playing a game of cards, the deck is shuffled before each new hand is played. Shuffling rearranges the cards so you are dealt a new set of cards with which to play. Some hands are better than others; they are the winning ones. Other combinations are not so good, so sometimes you lose.

Meiosis is a process which reshuffles genetic information (chromosomes). In this case, the hands being played are the offspring produced as a result of the information they receive. In any population there are differences among the individuals caused by the variety of information possible.

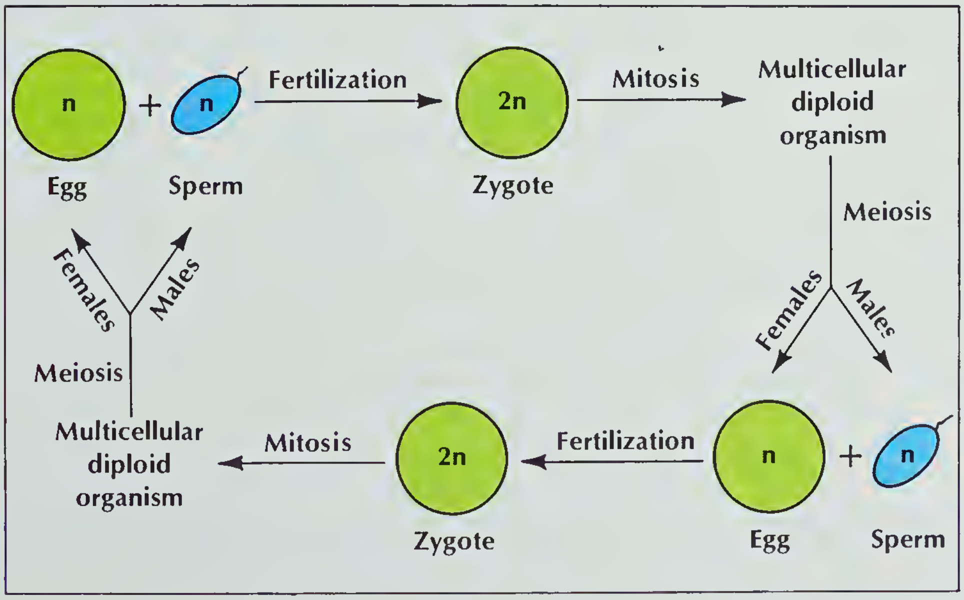

n
+
n
Egg
Sperm
Fertilization
2n
Zygote
Mitosis
Multicellular diploid organism
Meiosis
Females
Males
n
+
n
Egg
Sperm
Fertilization
2n
Zygote
Mitosis
Multicellular diploid organism
Meiosis
Females
Males

FIGURE 6-19. Organisms develop by mitosis and produce offspring by the union of eggs and sperm. Eggs and sperm are produced by meiosis.

Variation is important for survival.

How is this variation important? *Variation promotes a better chance for survival of some offspring should changes in the environment occur.* By keeping many different "hands" in the game, nature decreases the chances of too many losers. Adaptation depends on variety.

## 6:12 Meiosis and Variation

How does meiosis increase variety? Recall that information for the same trait is carried on each member of a pair of chromosomes. An example of the variety of chromosome possibilities is diagrammed in Figure 6-20. The two pairs of chromosomes in the mother's cells are *A* and *a*, *B* and *b*. *A* and *a* are homologous chromosomes which represent two chromosomes carrying the same trait but with different information. *B* and *b* represent a different homologous pair for another trait. The chromosomes in the father's cells are the same. After meiosis, four possible combinations of chromosomes exist among the gametes—*AB*, *Ab*, *aB*, and *ab*.

Meiosis can produce gametes with new combinations of chromosomes.

The particular chromosomes in a gamete depend on how they line up at metaphase I. If both *A* and *B* chromosomes lie on the same side of the "equator," they will both be pulled to the same end of the cell. Chromosomes *a* and *b* will be pulled to the other end of the cell. As a result, two gametes produced will be *AB* and two will be *ab*. However, if *A* and *b* are on the same side, some gametes produced will be *Ab*, and the other gametes produced will be *aB*.

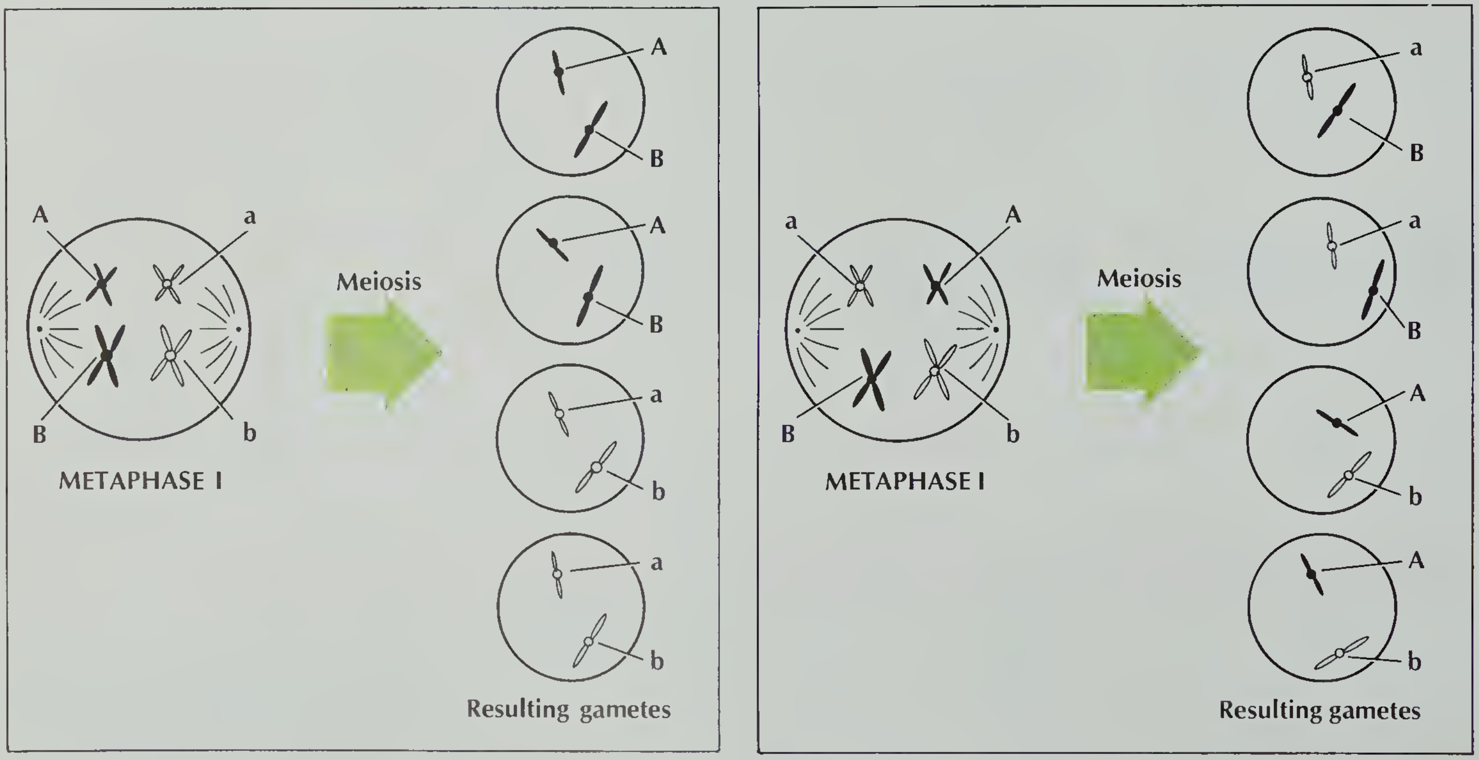


**FIGURE 6-20. Chromosome combinations in gametes depend on how homologs line up during metaphase I of meiosis.**

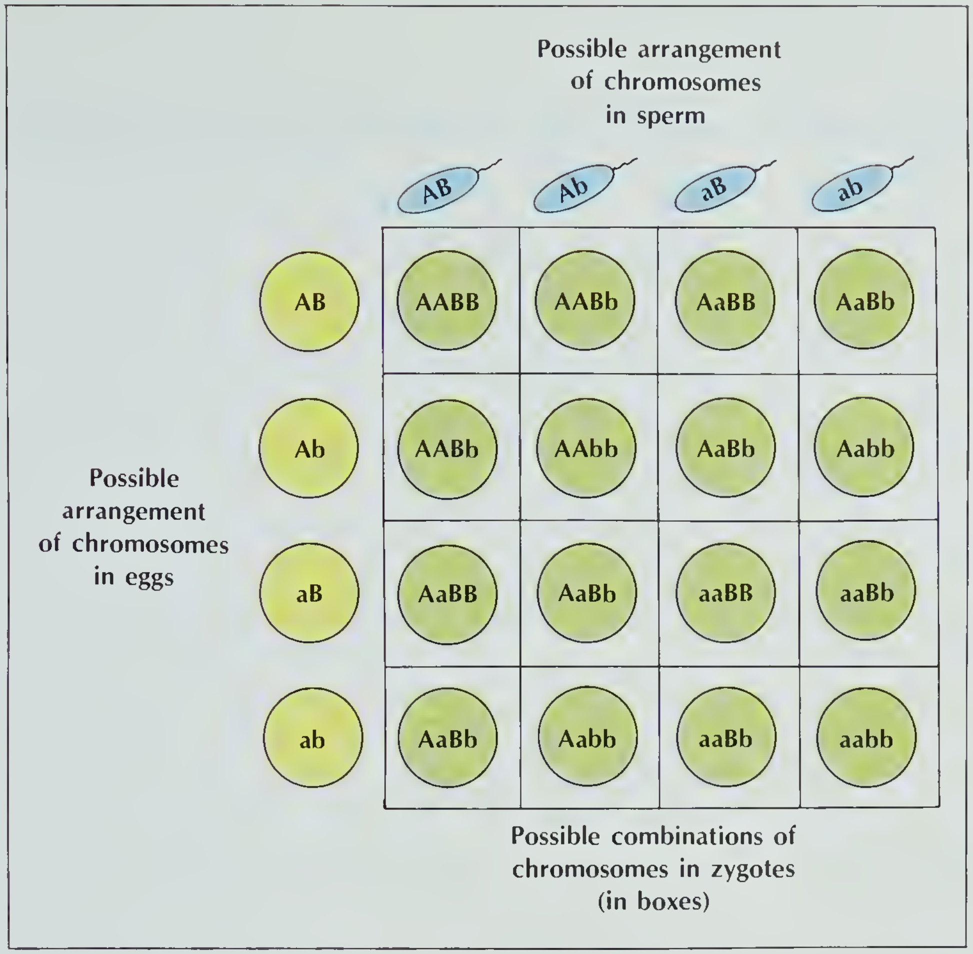

Possible arrangement of chromosomes in sperm
AB
Ab
aB
ab
Possible arrangement of chromosomes in eggs
AB
Ab
aB
ab
AABB
AABb
AaBB
AaBb
AABb
AAbb
AaBb
Aabb
AaBB
AaBb
aaBB
aaBb
AaBb
Aabb
aaBb
aabb
Possible combinations of chromosomes in zygotes (in boxes)

**FIGURE 6-21.** When gametes contain different combinations of chromosomes, fertilization leads to genetic recombination and increases variety among offspring.

There are nine different combinations of a and b chromosomes possible in the zygote including *AABB*, *AaBb*, and *aabb* (Figure 6-21). Eight of these zygote combinations are different from the parental combination. Thus, different combinations of features may appear among the offspring. Some combinations may be more useful to an organism's survival than others. This reshuffling of genetic instructions is referred to as **genetic recombination** (ree kahm buh NAY shun). In meiosis, recombination between parts of certain chromosomes also occurs in prophase I and adds to variability (Section 8:6).

Zygotes usually contain combinations of chromosomes different from those in the cells of the parents.

## REVIEWING YOUR IDEAS

12. Distinguish between monoploid and diploid numbers. How do gametes differ from other body cells?
13. What is meiosis? Why is it necessary? Where does it occur?
14. What is synapsis? What is a tetrad?
15. How does meiosis differ in males and females?
16. How does meiosis differ from mitosis?
17. What is genetic variability? Why is it a benefit that meiosis promotes variability?

# CHAPTER REVIEW

## SUMMARY

1. For several centuries, some biologists believed that certain living things were produced by spontaneous generation.
2. Redi showed that maggots are not spontaneously generated.
3. Leeuwenhoek's discovery of microorganisms caused the debate about spontaneous generation to continue.
4. Finally, in 1864, Pasteur conducted experiments that showed that microorganisms are not spontaneously generated, and that led to the theory of biogenesis.
5. Mitosis is the process which results in the replication and equal distribution of chromosomes to new nuclei.
6. Replication of chromosomes occurs during interphase, the period between mitoses.
7. The four phases of mitosis are prophase, metaphase, anaphase, and telophase.
8. Mitosis results in genetic continuity.
9. Each type of organism has a certain number of chromosomes.
10. Fertilization of an egg by a sperm results in the formation of a diploid zygote.
11. Meiosis is a process in which gametes having the monoploid number of chromosomes are produced. It occurs in two successive stages.
12. Meiosis and fertilization contribute to variation among offspring.

## LANGUAGE OF BIOLOGY

anaphase
biogenesis
cell plate
centromere
chromatid
chromatin
daughter cell
diploid
gamete
genetic recombination
homologs
interphase
meiosis
metaphase
mitosis
monoploid
ovum
prophase
sperm
spindle
spontaneous generation
telophase
tetrad
zygote

## CHECKING YOUR IDEAS

*On a separate paper, complete each of the following statements with the missing term(s). Do not write in this book.*

1. Mitosis of a *2n* cell results in the production of cells with a(n) ______ number of chromosomes.
2. Pasteur's experiments led to the theory of ______.
3. Meiosis in animals produces cells called ______.
4. Replication of chromosomes occurs during ______.
5. ______ of chromatids attach to spindle fibers.
6. During telophase a(n) ______ forms between the poles of plant cells.
7. Meiosis and fertilization promote ______ among organisms.
8. Cells produced from a *2n* cell by meiosis have a(n) ______ number of chromosomes.
9. ______ is the idea that living things arise from nonliving things.
10. The chromosomes of a matching pair are called ______.

## EVALUATING YOUR IDEAS

1. What was Aristotle's mistaken belief about where living things come from?
2. Did Redi disprove the theory of spontaneous generation? Explain. What important role did Redi play in the history of spontaneous generation?
3. Write an essay about Pasteur's experiment that disproved spontaneous generation. Discuss his equipment, the reasons for his procedure, and his results and their significance.
4. Why is the theory of biogenesis important?
5. How are the cell theory and the theory of biogenesis related?

## CHAPTER REVIEW

6. Describe the events of mitosis: (a) interphase, (b) prophase, (c) metaphase, (d) anaphase, and (e) telophase.
7. How does mitosis in plant cells differ from mitosis in animal cells?
8. What is genetic continuity? How does mitosis contribute to genetic continuity?
9. What are homologous chromosomes? How are homologs the same? How are they different?
10. In a given organism, the diploid number of chromosomes is 12. How many chromosomes will a gamete produced by this organism contain? Explain.
11. What is the origin of each member of a homologous pair of chromosomes?
12. Why is it important that a human egg or sperm contain the monoploid set of chromosomes rather than just any 23?
13. Describe the events of meiosis: (a) prophase I, (b) metaphase I, (c) anaphase I, and (d) telophase I as they occur in a male.
14. Compare meiosis II with mitosis.
15. How does meiosis in a female differ from meiosis in a male?
16. In terms of genetic continuity, summarize the relationship among meiosis, fertilization, and mitosis.
17. How does meiosis contribute to genetic recombination?
18. Why does asexual reproduction (mitosis) offer little opportunity for variety among offspring? Can you think of ways in which there is variation in mitosis?

## APPLYING YOUR IDEAS

1. Supporters of spontaneous generation claimed that air must be present for the process to occur. Do you think this idea was good science? Explain.
2. Explain how Redi's experiments made use of the elements of the scientific method.
3. Using the same procedure and equipment as Pasteur, what control could be used to show that spores are the "parents" of microorganisms?
4. Make a series of labeled drawings illustrating mitosis in a cell with a $2n$ of 6.
5. Make a series of labeled drawings illustrating meiosis in a male cell with a $2n$ of 6. Compare your drawings with the drawings in question 4.
6. How is the structure of a sperm cell adapted to its function? An egg?
7. List several examples of variations among organisms. Choose one feature and explain how a variation in this trait might be important in terms of a possible change in the environment.
8. Suppose a cell had four chromosomes of each type instead of two. How many chromosomes of each type would be in the daughter cells produced by mitosis?

## EXTENDING YOUR IDEAS

1. Prepare your own mitosis slides from onion root tips which you grow.
2. Salivary glands of fruit flies have giant chromosomes. Describe the structure of these chromosomes either by using library sources or, preferably, by making and examining slides of them.
3. Design and conduct an experiment about spontaneous generation of microorganisms. Consider variable factors such as presence of air, thorough boiling of infusions, and types of nutrients.

## SUGGESTED READINGS

Angyal, Jennifer, *Mitosis and Meiosis Illustrated*, Burlington, NC, Carolina Biological Supply Co., 1980.

Dubos, Rene, *Louis Pasteur: Free Lance of Science*. New York, Charles Scribner's Sons, 1976.

John Colwell for Grant Heilman

*Offspring inherit traits from their parents. This inheritance of traits gives parents and offspring many features in common. Yet, no two living things are exactly alike. Differences exist among parents and offspring, between offspring, and between different types of organisms. How do organisms of the same type differ? How do you differ from your brothers and sisters, your cousins, or your friends?*

Chapter 7

# PRINCIPLES OF HEREDITY

Genetic information is passed from parents to offspring. How this process occurs was not known until this century. In 1866, Gregor Mendel (1822-1884) reported the results of eight years of study and thought. His work was ignored until 1900, but when discovered, it was seen as a breakthrough. The study of **genetics** (juh NET ihks), the science of heredity, as a distinct branch of biology resulted.

To appreciate genetics, it is helpful to learn how Mendel arrived at his conclusions. Keep in mind the steps of good science. All of them are shown in Mendel's creative work.

**GOAL:** You will gain an understanding of genetics and probability and learn to solve genetic problems.

## ORIGIN OF GENETICS

### 7:1 Mendel's Experiments

Mendel worked with the common pea plant. Pea plants are grown easily and produce large numbers of offspring in a short time. Mendel found that traits (characteristics) are hereditary and that they are transmitted (passed) from generation to generation. He also found that many traits exist in either of two possible forms. For example, pea seeds are either round or wrinkled. The stems of pea plants are either tall or short. Mendel set out to determine how traits were transmitted from parents to offspring.

In pea plants, several traits exist in either of two possible forms.

It is a good thing that Mendel chose to work with a large number of plants. Perhaps he realized that the greater the number of plants, the greater the chances that his results would be more meaningful. He was looking for general trends because he wanted to make a basic set of rules about the transmission of traits. In all, Mendel worked with seven traits in his first experiments on the pea plants (Figure 7-1).

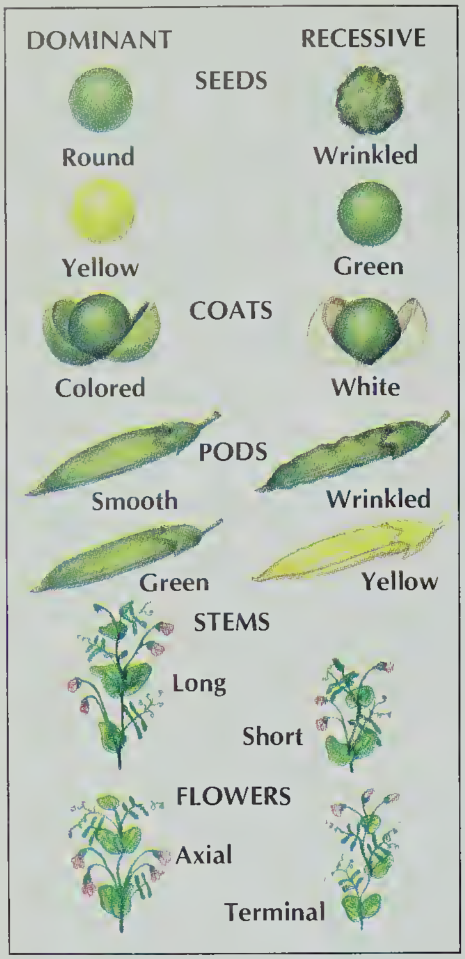


**FIGURE 7-1. Mendel worked with seven pea plant traits in his first experiments. Each trait could appear in one of two forms.**

## 7:2 Mendel's Results

Pea plants reproduce sexually. Both male and female sex organs are in the same flower. Normally, male gametes fertilize eggs of the same flower. After many generations, offspring still have the same features as the parents. Such plants are said to be pure.

Mendel wished to cross a plant having one certain trait with a plant having the opposite trait. For example, he wanted to cross plants which produced round seeds with plants which produced wrinkled seeds. Therefore, he transferred the male gametes (pollen) of one plant to another plant (Figure 7-2).

In some cases, the pollen was obtained from round-seeded plants and transferred to wrinkled-seeded plants. The opposite combination also was done. Mendel found that in every case, the **parental cross** (P) yielded offspring which all had round seeds. The offspring of a parental cross are the **first filial** (FIHL ee ul), or **$F_1$, generation.**

Mendel was impressed that there were no wrinkled-seeded plants in the $F_1$ generation. He then allowed members of the $F_1$ generation to reproduce in the usual fashion.

In the $F_2$ generation, a ratio of three round-seeded plants to one wrinkled-seeded plant appeared.

The offspring of this cross are called the **second filial**, or $F_2$, **generation.** The results of this cross were very revealing. Of the 7324 offspring produced, 5474 plants had round seeds and 1850 had wrinkled seeds. These numbers give a ratio very close to three

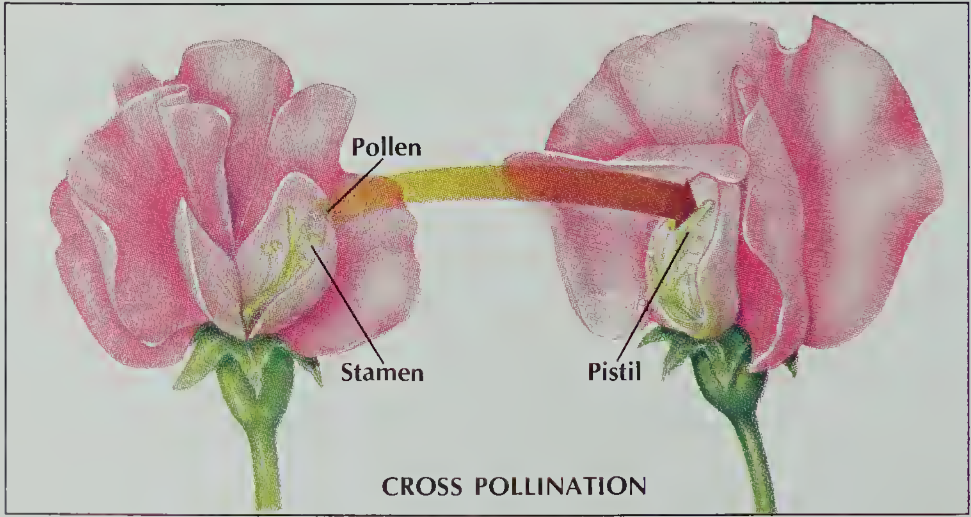


**FIGURE 7-2. Mendel cross-pollinated pea plants by transferring the pollen from one plant to another plant. In this way, he could determine what types of offspring are produced from these parents.**

round-seeded plants to one wrinkled-seeded plant. Mendel also repeated these experiments with the other pairs of traits and obtained a 3:1 ratio in each case.

Mendel noted that for each trait there is one form which "dominates" the other. On the basis of the results of the $F_1$ generation, the trait for round seeds is the **dominant** (DAHM uh nunt) **trait.** The other trait, wrinkled seeds, which disappears in the $F_1$ generation, is called a **recessive** (rih SES ihv) **trait.** Mendel generalized this idea in his **law of dominance** (DAHM uh nunts): *one form of a hereditary trait, the dominant trait, dominates or prevents the expression of the recessive trait.*

## 7:3 Mendel's Hypothesis

In Mendel's crosses the recessive trait disappeared in the $F_1$ generation but reappeared in the $F_2$ generation. To explain this result, Mendel made certain *assumptions*. Each pea plant is produced as a result of the union of a sperm and an egg. Thus, he reasoned that for every trait there must be two governing factors. One must come from the sperm and one must come from the egg. He called the factors **characters**, but we now call them **genes**. Mendel represented the genes by symbols. A dominant gene was represented by a capital letter. A recessive gene was represented by the same letter as the dominant gene but in lowercase. For example, if the gene for round seed shape (dominant) were *R*, then the gene for wrinkled seeds (recessive) would be *r*. The two genes combine in the fertilized egg so that each new pea plant contains two genes for each trait (Figure 7-3).

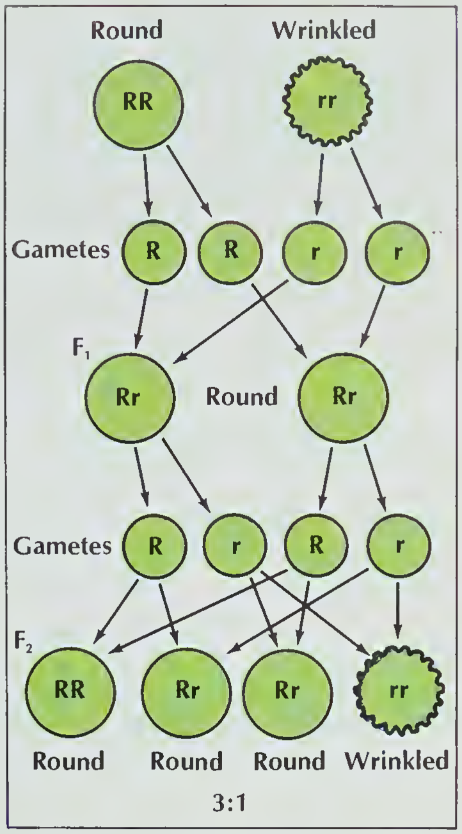


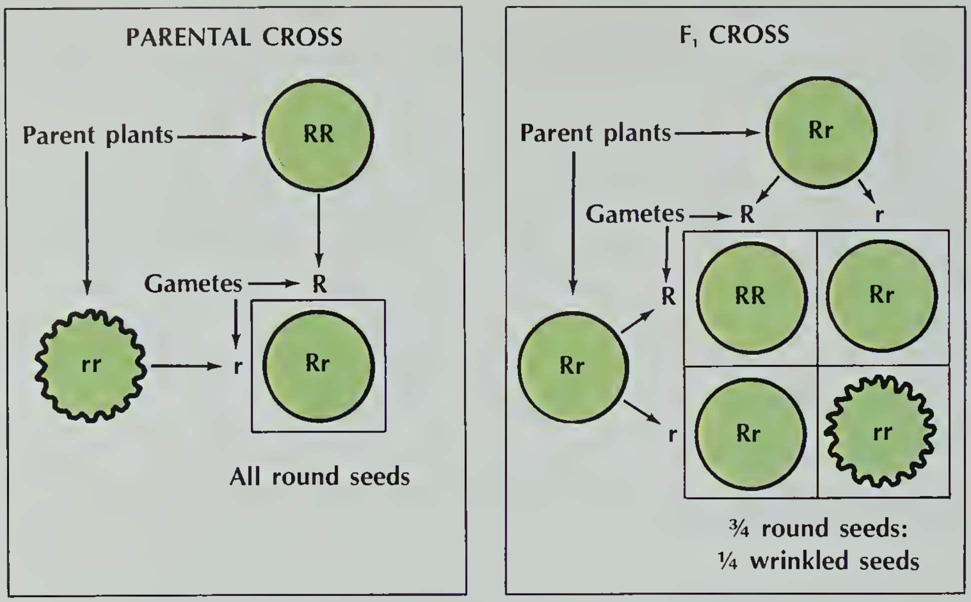
**FIGURE 7-3. Mendel's analysis of his experimental results can be set up in a flow chart that shows parents, gametes, and possible offspring.**

In Mendel's experiments, the pure parental plants each had the same genes. Round-seeded plants (dominant) were *RR*. Wrinkled-seeded plants (recessive) were *rr*. Mendel reasoned that the two genes segregate (separate) during gamete formation. Sperms and eggs would have just one gene for each trait. Thus, the gametes of round-seeded parents should have the *R* gene, and gametes of wrinkled-seeded parents should have the *r* gene. As a result, all $F_1$ plants should be *Rr*, the only possible combination. Because the *R* gene is dominant to the *r* gene, all $F_1$ plants would have round seeds.

Mendel reasoned that the two genes governing each trait segregate from each other during gamete formation.

If Mendel's assumptions were correct, all $F_1$ plants (*Rr*) should produce half their gametes with the *R* gene and half with the *r* gene. There would be three possible combinations in the $F_2$ generation—*RR*, *Rr*, and *rr*. The chances of *R* and *r* gametes combining would be twice as great as other possible combinations. These possibilities can be expressed as a ratio—1 *RR* : 2 *Rr* : 1 *rr*. Both *RR* and *Rr* plants will produce round seeds, while *rr* plants will produce wrinkled seeds. This result is a ratio of 3 round-seeded plants : 1 wrinkled-seeded plant.

**FIGURE 7-4. Combinations of characters among offspring can be determined by using Punnett squares. Sperm and egg possibilities are listed along the top and left side of the square. Possible offspring are shown inside the Punnett square.**



Punnett squares can be used to solve genetics problems.

Results of genetics problems can be shown with Punnett (PUN ut) squares (Figure 7-4). A **Punnett square** is a chart used to determine the possible combinations of characters among offspring. Across the top of the square are written the gametes produced by one parent. The gametes produced by the other parent are listed along the left side of the square. The square is then filled in by listing all the possible combinations of gametes. Each square in the chart represents a *possible* zygote.

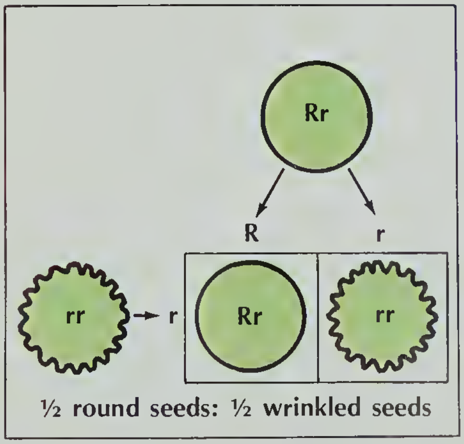
## 7:4 The Test of Segregation

Law of segregation: During gamete formation, the pair of genes responsible for each trait segregate so that each gamete contains only one gene for each trait.

Mendel was able to explain what he observed in his experiments. His laws of dominance and his hypothesis of gene segregation into gametes grew from his experiments. Alone, these did not mean that his explanation was correct, so a test was needed to confirm his hypothesis. Mendel did this test after predicting the outcome of another cross.

If $F_1$ generation round-seeded plants were crossed with wrinkled-seeded plants, Mendel thought that he should get ratios different from the other ones. According to his hypothesis, $F_1$ round-seeded plants are *Rr* and wrinkled-seeded plants are *rr*. Round-seeded plants produce both *R* and *r* gametes while wrinkled-seeded plants produce only *r* gametes. Mendel predicted that the possible combinations would be *Rr* (round) and *rr* (wrinkled) and that the number of each should be the same (Figure 7-5). When Mendel performed the experiment, this result did occur. He obtained about half (50%) round-seeded and half (50%) wrinkled-seeded plants. The same ratio was observed when he used other traits.

**FIGURE 7-5. Mendel predicted the results of this cross (*Rr* × *rr*). His results matched his predictions and verified his assumptions.**



As a result of his experiments, Mendel assumed his hypothesis was correct. His hypothesis led to the **law of segregation** (seg rih GAY shun): *during gamete formation the pair of genes responsible for each trait separate so that each gamete contains only one gene for each trait.* The gametes unite to produce predictable ratios of traits among the offspring.

## 7:5 Terminology

Mendel's "characters" may take different forms, such as dominant and recessive. These forms of genes for a trait are **alleles** (uh LEELZ). Thus, the trait expressed as seed shape is determined by two alleles, *R* and *r*. The combination of alleles which an organism has is called its **genotype** (JEE nuh tipe). The genotype for any trait includes both alleles. For seed shape in pea plants, the possible genotypes are *RR*, *Rr*, and *rr*. The physical or visible feature which each genotype determines is called the **phenotype** (FEE nuh tipe). Round seeds and wrinkled seeds are phenotypes determined by the alleles *R* and *r*. Round seeds is the phenotype determined by the genotypes *RR* and *Rr*. Wrinkled seeds is the phenotype determined by the genotype *rr*. Notice that different genotypes may result in the same phenotype.

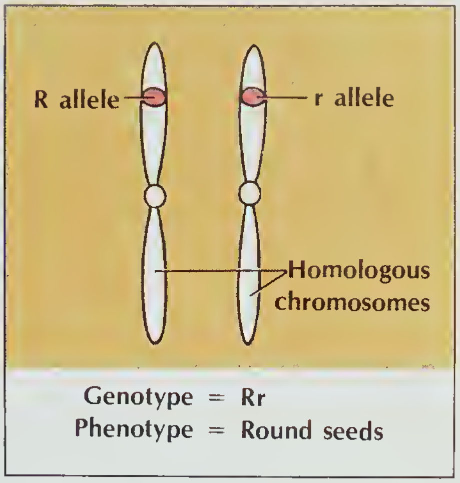


**FIGURE 7-6. Terminology: A genotype represents the alleles on homologous chromosomes that give a certain phenotype.**

A genotype indicates the combination of alleles an organism has for a given trait.

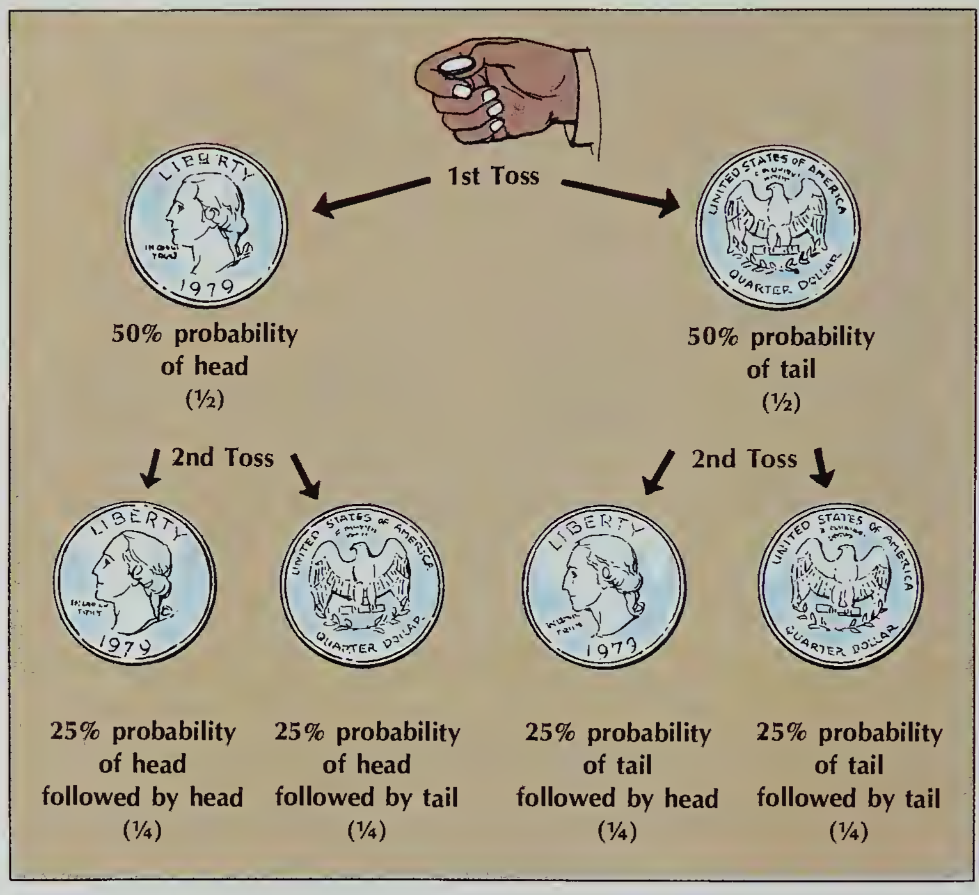
A phenotype is the trait determined by a particular genotype.

When each cell of an organism contains two alleles that are the same, the organism is **homozygous** (hoh muh ZI gus) for that trait. *RR* and *rr* are both homozygous genotypes. To avoid confusion, the terms **homozygous dominant** and **homozygous recessive** are used. When each cell of an organism contains one of each kind of allele, it is **heterozygous** (het uh roh ZI gus). A plant with the genotype *Rr* is heterozygous. You should learn these terms for your work in genetics.

### REVIEWING YOUR IDEAS

1. What did Mendel notice about the appearance of hereditary traits? What did Mendel try to find? Did he succeed?
2. Why did Mendel transfer the male gametes of one plant to another plant?
3. State the law of dominance.
4. How are dominant and recessive traits represented?
5. What led Mendel to form his law of segregation? How did Mendel test the law of segregation?
6. Define allele, genotype, phenotype, homozygous, and heterozygous.
7. In a certain organism, the gene for tall, *T*, is dominant to the gene for short, *t*. Write the genotype and phenotype for an organism that is (a) heterozygous, (b) homozygous dominant, and (c) homozygous recessive.

**FIGURE 7-7.** Each toss of a coin has a 50% probability of being a head (or a tail). To find the probability of combinations of tosses in a row, use the product rule. What is the probability of tossing a tail followed by a head?


1st Toss
50% probability of head (½)
50% probability of tail (½)
2nd Toss
2nd Toss
25% probability of head followed by head (¼)
25% probability of head followed by tail (¼)
25% probability of tail followed by head (¼)
25% probability of tail followed by tail (¼)

## SOLVING GENETICS PROBLEMS

### 7:6 Probability

The product rule: The probability of two or more events occurring together is the product of the individual probabilities of each event occurring alone.

When you toss a coin, the chances are equal that you will get a head or a tail. Stated another way, there is a fifty—fifty chance of getting a head (or a tail). There is an equal **probability** of tossing either a head or a tail. This probability also can be written 1 head: 1 tail, or ½ heads: ½ tails. These expressions say the same thing. It is simply a matter of chance whether a head or a tail appears.

What are the chances of tossing two heads in a row? The answer is the product of (multiply) the individual probabilities. This rule is called the **product rule.** Each time the coin is tossed, the chance of getting a head is ½. To find the probability of tossing two heads in a row, multiply ½ times ½. The answer is ¼. *Previous tosses of the coin do not influence individual tosses.* Even if you tossed heads five times in a row, the chance that the next toss would be a head is still ½. But, what are the chances of tossing five heads in a row? Using the product rule, the answer is ½ × ½ × ½ × ½ × ½ or ⅟32.

Probability is important in genetics and in solving genetics problems. The law of segregation states that alleles separate during gamete formation. Each gamete gets its allele for a trait purely by chance. Consider the $F_1$ generation in Mendel's experiments in which each plant had the genotype $Rr$. Gametes produced by these plants must have had either the $R$ or $r$ allele. Like a two-sided coin, the chances are equal for $R$ and $r$ to appear in a gamete so the ratio of alleles produced by the $F_1$ plants should be ½ $R$: ½ $r$. One half the gametes, by chance, will contain the $R$ allele and one half will contain the $r$ allele.

The laws of probability are used widely in the study of genetics.

How can this idea be used to predict the results of breeding plants or animals? Consider ½ $R$ and ½ $r$ as the chances of the gametes being produced by parents with the $Rr$ genotype. The ratios of genotypes and phenotypes of their offspring can be determined by using the product rule. The possible combinations of the alleles in the next generation can be found in the following way:

(1) Probable distribution of alleles:
½ $R$ + ½ $r$ (for both parents)
(2) Probable combinations of alleles:

$$\begin{array}{r} \tfrac{1}{2}\,R + \tfrac{1}{2}\,r \\ \times\ \tfrac{1}{2}\,R + \tfrac{1}{2}\,r \\ \hline + \tfrac{1}{4}\,Rr + \tfrac{1}{4}\,rr \\ \tfrac{1}{4}\,RR + \tfrac{1}{4}\,Rr \\ \hline \tfrac{1}{4}\,RR + \tfrac{1}{2}\,Rr + \tfrac{1}{4}\,rr \end{array}$$

(3) Genotypes:

$$\tfrac{1}{4}\,RR + \tfrac{1}{2}\,Rr + \tfrac{1}{4}\,rr$$

(4) Phenotypes:

¾ round: ¼ wrinkled

Note that the genotypes $RR$ and $Rr$ produce the same phenotype, round seeds.

Both the genotypic ratio and the phenotypic ratio should add up to a total of one. Check your work.

This answer is the same ratio which Mendel obtained. Do you see why it was good that he worked with many plants? For example, suppose Mendel had only examined four offspring of the $Rr$ by $Rr$ cross. It is possible that the four offspring would have all been $rr$, all wrinkled. This answer would have been as far as possible from the expected 3:1 ratio. As the number of offspring examined increases, the chance that the results will vary from the expected decreases. Mendel examined hundreds of offspring to get his results. Segregation and combination occur by chance so the larger the number of offspring observed, the closer the result will be to the 3:1 ratio.

Expected results are more likely to be obtained when large numbers of individuals are considered.

Compare this method with the Punnett square method. Listing the possible gametes across the top and side of the square is like following the rules of probability. By using the Punnett square method, you actually are multiplying probabilities (the product rule).

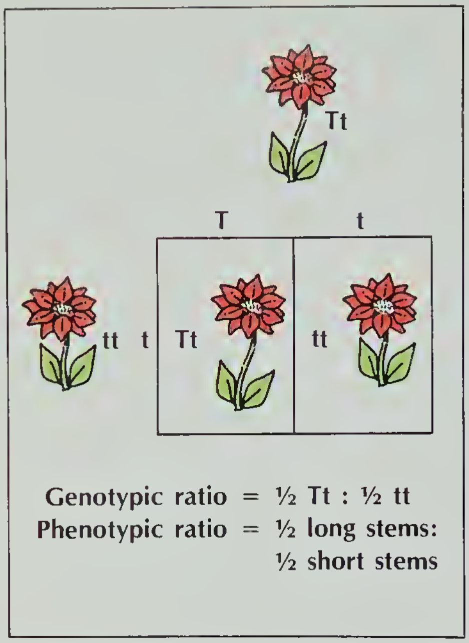

Tt
T
t
tt
t
Tt
tt
Genotypic ratio = ½ Tt : ½ tt
Phenotypic ratio = ½ long stems: ½ short stems

**FIGURE 7-8. In this Punnett square solution to Sample Problem 1, notice that half the possible offspring are *Tt* and half are *tt*.**

## 7:7 Ratios

Often a geneticist (juh NET uh sust) is interested in finding probable ratios of the genotypes and phenotypes among the offspring of a cross with one trait. The **genotypic** (jee nuh TIHP ihk) **ratio** is the result obtained by the product rule. The **phenotypic** (fee nuh TIHP ihk) **ratio** is found by interpreting the genotypes. Study the following sample problem.

*Sample Problem 1:* In a certain plant, tall stems ($T$) are dominant to short stems ($t$). A farmer crosses a short-stemmed plant with a heterozygous long-stemmed plant. What are the expected genotypic and phenotypic ratios?

*Solution:*

(1) Write the genotype of each parent.

short stem: $tt$
long stem: $Tt$

(2) Determine the probable distribution of alleles in the gametes.

$$\text{short} = tt \rightarrow 1/1t$$
$$\text{long} = Tt \rightarrow \tfrac{1}{2}T + \tfrac{1}{2}t$$

(3) Using the product rule, multiply to find the probable combination of alleles (genotypic ratio).

$$\begin{array}{r} \tfrac{1}{2}T + \tfrac{1}{2}t \\ \times \tfrac{1}{1}t \\ \hline \tfrac{1}{2}Tt + \tfrac{1}{2}tt \end{array}$$

(4) Interpret the genotypes to find the phenotypic ratio.

½ $Tt$ = long stems
½ $tt$ = short stems

Therefore, the phenotypic ratio is ½ long stems: ½ short stems.

Figure 7-8 shows the solution to this problem by the Punnett square method.

### REVIEWING YOUR IDEAS

8. What is the probability of tossing a coin and getting heads three times in a row?
9. What is the chance that the next toss will be heads? What is the chance that the next toss will be tails?
10. What is the probable ratio of alleles produced in the gametes of an organism with the genotype (a) *MM*, (b) *Mm*, and (c) *mm*?
11. Why was it good that Mendel worked with large numbers of plants?

12. In a certain plant, yellow fruit, *Y*, is dominant to white fruit, *y*. A heterozygous plant with yellow fruit is crossed with a plant with white fruit. Find the probable genotypic and phenotypic ratios resulting from this cross.
13. Find the probable genotypic and phenotypic ratios expected from crossing two heterozygous plants of Problem 12.

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W. Atlee Burpee Co.

George W. Parke Seed Co.

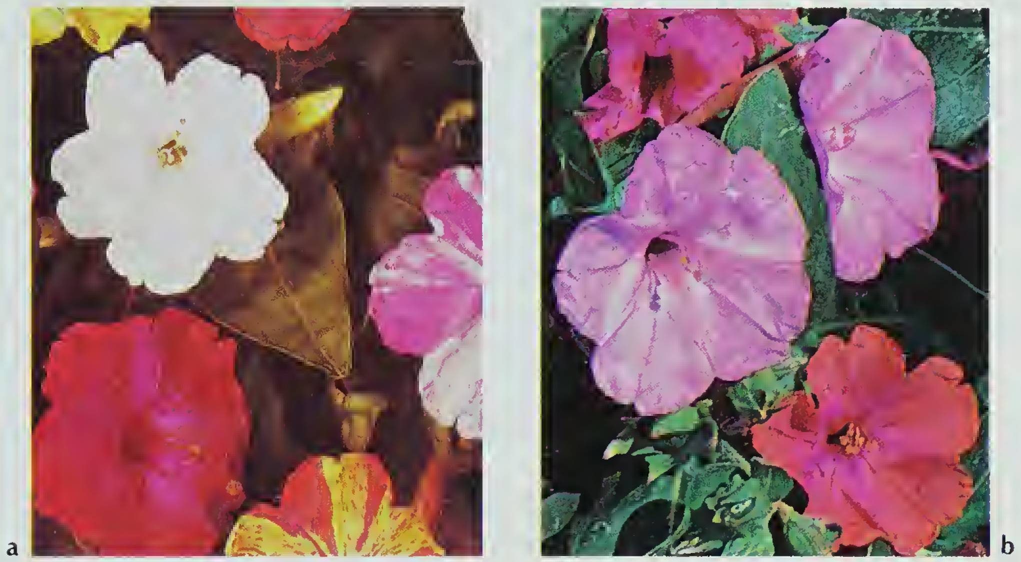


**FIGURE 7-9. (a) In four o'clocks, the gene for red flowers is incompletely dominant over the gene for white flowers. (b) The heterozygote has pink flowers.**

## 7:8 Incomplete Dominance

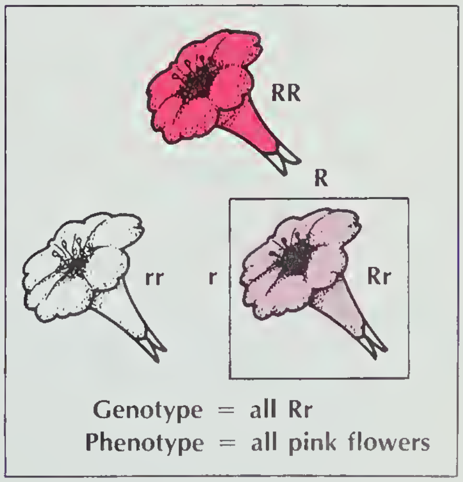
Sometimes heterozygous alleles result in a phenotype between the dominant and recessive traits. For example, in some flowers, the alleles for red and white produce pink flowers when heterozygous. This phenomenon is called **incomplete dominance**. To solve a genetics problem involving incomplete dominance, proceed in the same manner as the sample problem. However, the heterozygous condition results in a new trait.

*Sample Problem 2:* In four-o'clocks the genes for red flowers, *R*, and white flowers, *r*, are incompletely dominant to one another. The heterozygous condition results in pink flowers. A gardener crosses a red four-o'clock with a white one. What are the expected genotypes and phenotypes of the offspring?

*Solution:* (1) The parental genotypes must be *RR* for the red flower and *rr* for the white. Why? (2) The *RR* flowers produce all *R* gametes and the *rr* flowers produce all *r* gametes. (3) Therefore, the genotype is all *Rr*. The genotype interpreted as phenotype gives all pink flowers.

In incomplete dominance, the heterozygous condition is intermediate between or different from the dominant and recessive traits.

**FIGURE 7-10. The Punnett square solution to Sample Problem 2 illustrates incomplete dominance.**

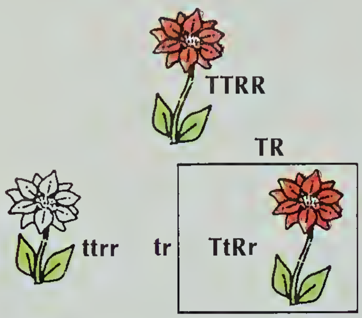


## 7:9 Two Traits

After Mendel's first set of experiments, he studied the inheritance of two traits at once. For example, what types of plants would develop from a cross between a tall, red-flowered plant (*TTRR*) and a short, white-flowered plant (*ttrr*)? Remember, *each gamete must contain one allele for each trait* (law of segregation). Therefore, the gametes of the tall, red parent should have the alleles *T* and *R* and the short, white plant should produce gametes with *t* and *r* alleles. If they do, $F_1$ plants would all have the genotype *TtRr* and the phenotype tall and red (Figure 7-12). Mendel found these results.

The $F_1$ cross presented another problem to Mendel. The $F_1$ plants had the genotype *TtRr*. He knew that gametes produced by these plants must contain one of each kind of allele. But, do the alleles segregate independently of one another during gamete formation? Or do they stay in the same combination (*TR* or *tr*)? Mendel hypothesized that they segregate independently so that the possible gametes would be *TR, Tr, tR,* and *tr*. The $F_2$ generation should show a phenotypic ratio of 9:3:3:1 (Figure 7-13). Again, experiments verified this prediction. The **law of independent assortment** states that *alleles segregate independently during gamete formation.*

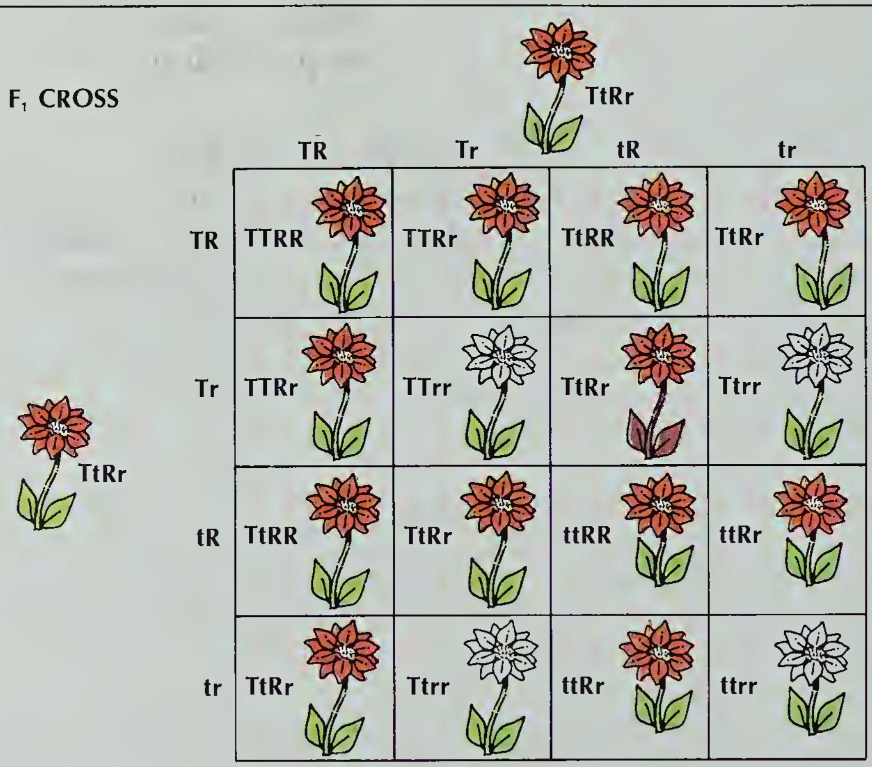
PARENTAL CROSS



Genotype = all TtRr
Phenotype = all tall and red

**FIGURE 7-11. The $F_1$ generation of a parental cross involving two traits is shown in this Punnett square.**

$F_1$ CROSS



Genotypic ratio = 1/16 TTRR : 1/8 TTRr : 1/8 TtRR : 1/4 TtRr : 1/16 TTrr:
1/8 Ttrr : 1/16 ttRR : 1/8 ttRr : 1/16 ttrr
Phenotypic ratio = 9/16 tall and red : 3/16 tall and white :
3/16 short and red : 1/16 short and white

**FIGURE 7-12. The $F_2$ generation of an $F_1$ cross involving two traits is shown in this Punnett square. You can see how Punnett square solutions become more involved as more traits are considered in a cross.**

Grant Heilman

**FIGURE 7-13.** Guinea pigs are animals in which different observable traits, such as coat color, can be studied.

Because alleles are sorted in this manner, genetics problems involving two traits are solved easily. The problem is a little longer, but no more difficult. Each trait is treated separately. Then, using the product rule again, the probabilities of all four alleles combined can be determined.

*Sample Problem 3:* In guinea pigs, rough coat ($R$) is dominant to smooth coat ($r$). Black color ($B$) is dominant to albino ($b$). A heterozygous black, smooth male is bred to a heterozygous black, heterozygous rough female. What are the probable genotypic and phenotypic ratios among their offspring?

*Solution:*

(1) Genotypes:

$$\text{male: } Bbrr$$
$$\text{female: } BbRr$$

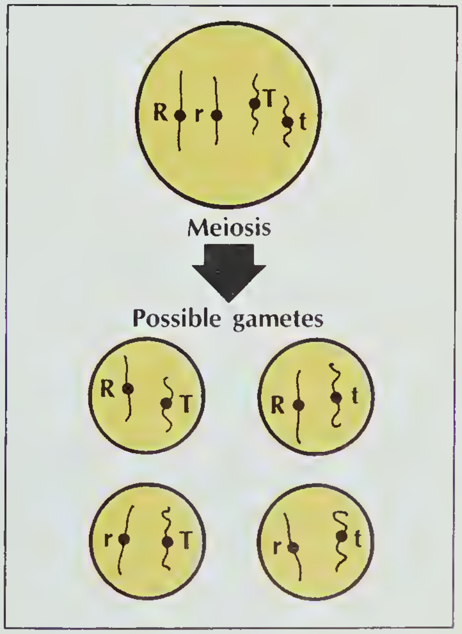
(2) Gametes produced for color ($B$ and $b$ alleles):

$$\text{male} = Bb \rightarrow \tfrac{1}{2}B + \tfrac{1}{2}b$$
$$\text{female} = Bb \rightarrow \tfrac{1}{2}B + \tfrac{1}{2}b$$

(3) Multiply to find the probable combinations of $B$ and $b$ alleles among offspring.

$$\begin{array}{r} \tfrac{1}{2}B + \tfrac{1}{2}b \\ \times\ \tfrac{1}{2}B + \tfrac{1}{2}b \\ \hline \tfrac{1}{4}BB + \tfrac{1}{4}Bb \qquad\qquad \\ \tfrac{1}{4}Bb + \tfrac{1}{4}bb \\ \hline \tfrac{1}{4}BB + \tfrac{1}{2}Bb + \tfrac{1}{4}bb \end{array}$$

**FIGURE 7-14.** A cell that is heterozygous for two traits could produce four different gamete types depending on how the chromosomes assort.



Use the product rule for the second trait.

(4) Repeat steps 2 and 3 for the other trait ($R$ and $r$ alleles).

$$\text{male} = rr \rightarrow \tfrac{1}{1}r$$

$$\text{female} = Rr \rightarrow \tfrac{1}{2}R + \tfrac{1}{2}r$$

$$\begin{array}{r} \tfrac{1}{2}R + \tfrac{1}{2}r \\ \times\ \tfrac{1}{1}r \\ \hline \tfrac{1}{2}Rr + \tfrac{1}{2}rr \end{array}$$

Use the product rule again to determine the probable combinations of all four alleles.

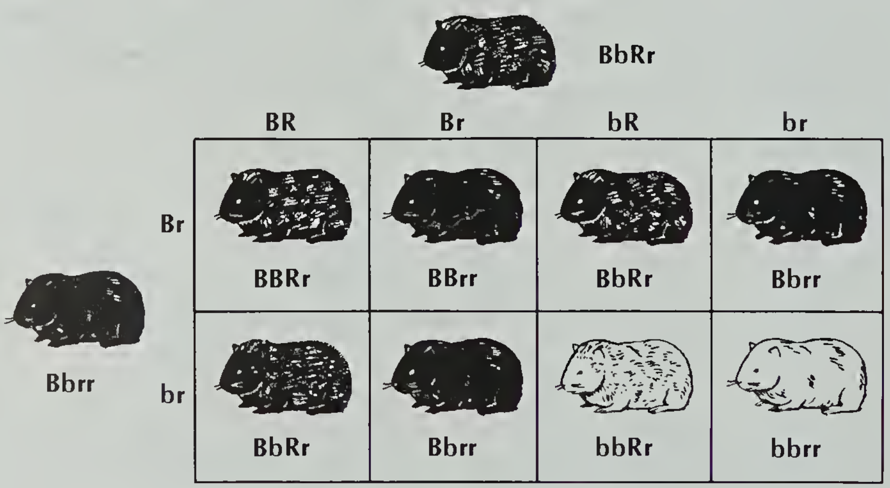
(5) Multiply each of these products to find the probable combinations of all four alleles (genotypic ratio).

$$\begin{array}{c} \tfrac{1}{4}BB + \tfrac{1}{2}Bb + \tfrac{1}{4}bb \\ \times\ \tfrac{1}{2}Rr + \tfrac{1}{2}rr \\ \hline \tfrac{1}{8}BBRr + \tfrac{1}{4}BbRr + \tfrac{1}{8}bbRr + \tfrac{1}{8}BBrr + \tfrac{1}{4}Bbrr + \tfrac{1}{8}bbrr \end{array}$$

(6) Interpret genotypes to find the phenotypic ratio.

$\tfrac{1}{8}BBRr$ = black and rough
$\tfrac{1}{4}BbRr$ = black and rough
$\tfrac{1}{8}bbRr$ = albino and rough
$\tfrac{1}{8}BBrr$ = black and smooth
$\tfrac{1}{4}Bbrr$ = black and smooth
$\tfrac{1}{8}bbrr$ = albino and smooth

The phenotypic ratio is 3/8 black and rough: 1/8 albino and rough: 3/8 black and smooth: 1/8 albino and smooth. Check the accuracy of the phenotypic ratio by adding the fractions. The sum should equal one: $\tfrac{3}{8} + \tfrac{1}{8} + \tfrac{3}{8} + \tfrac{1}{8} = \tfrac{8}{8} = 1$.



Genotypic ratio = 1/8 BBRr : 1/4 BbRr : 1/8 BBrr : 1/4 Bbrr : 1/8 bbRr : 1/8 bbrr

Phenotypic ratio = 3/8 black and rough : 1/8 albino and rough : 3/8 black and smooth : 1/8 albino and smooth

**FIGURE 7-15. The Punnett square solution to Sample Problem 3 shows the genotypes of a cross involving two traits. The phenotypes can be determined from the genotypes.**

## 7:10 Multiple Alleles

Often two alleles act together to produce a trait in an organism, but many traits are governed by more than two alleles, **multiple alleles**. Human blood type, for example, is controlled by three alleles, $I^A$, $I^B$, and $I^O$. The possible genotypes involving these alleles are $I^AI^A$, $I^BI^B$, $I^OI^O$, $I^AI^B$, $I^AI^O$, and $I^BI^O$. Both $I^A$ and $I^B$ are dominant to $I^O$. However, neither $I^A$ nor $I^B$ is dominant over the other. Therefore, four blood types are possible: A, B, AB, and O. These are the phenotypes. The genotypes that produce the blood types are listed in Table 7-1.

**TABLE 7-1. BLOOD TYPES**

| Phenotype | Genotype |
|---|---|
| A | $I^AI^A$, $I^AI^O$ |
| B | $I^BI^B$, $I^BI^O$ |
| AB | $I^AI^B$ |
| O | $I^OI^O$ |

*Sample Problem 4:* A woman who is known to have type B blood marries a man who has type A blood. They have five children, all with type AB blood. What are the most *probable* parental genotypes?

More than two alleles for a trait may be present in a population but an individual diploid organism has only two alleles for the trait.

*Solution:* Consider the genotype of the children. Each of them has type AB blood. Therefore, their genotype must be $I^AI^B$. Now consider the parental possibilities. The mother could be either $I^BI^B$ or $I^BI^O$. The father could have the genotype $I^AI^A$ or $I^AI^O$. That all their children have $I^AI^B$ indicates that both parents are probably homozygous. If either of the parents were heterozygous, then some other blood types would probably occur among the five children. The mother's genotype is probably $I^BI^B$ and the father's is probably $I^AI^A$.

If these parents have a sixth child whose blood type is O ($I^OI^O$), would you change your answer? Why or why not?

### REVIEWING YOUR IDEAS

✓14. In four-o'clocks the genes for red flowers, *R*, and white flowers, *r*, are incompletely dominant to one another. The heterozygous condition results in pink flowers. A gardener crosses two red four-o'clocks. What are the expected genotypes and phenotypes of the offspring?
15. State the law of independent assortment.
16. What are multiple alleles?

## CHAPTER REVIEW

### SUMMARY

1. The science of genetics began with the discovery in the early 1900's of Gregor Mendel's work.
2. Mendel studied the transmission of traits in pea plants and was the first to note that traits can exist in two possible forms. His work led to a statement of three main laws of inheritance.

## CHAPTER REVIEW

3. The three main laws of inheritance coming from Mendel's work are the laws of dominance, segregation, and independent assortment.
4. The law of dominance states that one form of a hereditary trait, dominant, prevents the expression of another form, recessive.
5. The law of segregation states that alleles separate in gamete formation and go to different gametes.
6. Alleles determine genotypes and phenotypes.
7. Laws of probability can be used to solve genetics problems.
8. Incomplete dominance occurs when one gene is not dominant over another.
9. The law of independent assortment says that segregation of alleles occurs independently of segregation of other alleles.
10. Incomplete dominance and multiple alleles are some ways in which genetic transmission can be complex.

## LANGUAGE OF BIOLOGY

alleles
dominant
gene
genotype
heterozygous
homozygous
incomplete dominance
law of dominance
law of independent assortment
law of segregation
multiple alleles
phenotype
Punnett square
recessive

## CHECKING YOUR IDEAS

*On a separate paper, indicate whether each of the following statements is true or false. Do not write in this book.*

1. Each gamete contains only one allele for each trait.
2. If the gene for yellow seeds, *Y*, is dominant to the gene for green seeds, *y*, then an organism which is *Yy* will have green seeds.
3. The organism described in question 2 is heterozygous.
4. Alleles segregate independently during gamete formation.
5. Actual results obtained from a cross are always the same as expected results.
6. By chance, one fourth of the gametes of an *Aa* organism will contain an *A* allele.
7. If two heterozygotes are crossed, half their offspring are expected to be heterozygous.
8. If an organism, *BB*, is crossed with an organism, *Bb*, all the offspring should be homozygous.
9. If two heterozygotes are crossed and one allele is dominant to the other, then one-half the offspring are expected to have the dominant trait.
10. The chances of tossing three coins and getting all heads is ⅙.
11. A gamete produced from an organism *AABB* contains two *A* genes and two *B* genes.
12. If two organisms with the genotype *AaBb* are crossed, a 9:3:3:1 phenotypic ratio is expected.
13. Parents with the genotype $I^AI^O$ and $I^BI^B$ can produce a child with type O blood.
14. Type AB blood results because the genes $I^A$ and $I^B$ show incomplete dominance.
15. If multiple alleles are present, an organism must contain three alleles for each trait.

## EVALUATING YOUR IDEAS

1. How were the results of Mendel's parental crosses unusual? How did Mendel interpret these results?
2. What happened when Mendel crossed members of the $F_1$ generation?
3. Why did Mendel assume that each organism has two characters for each trait?
4. How did Mendel test segregation?
5. Distinguish among the laws of dominance, segregation, and independent assortment.

## CHAPTER REVIEW

### APPLYING YOUR IDEAS

1. In a certain animal, black fur, *B*, is dominant to white fur, *b*. Determine the expected genotypic ratios and phenotypic ratios resulting from crosses between (a) homozygous black × white, (b) two heterozygous blacks, and (c) heterozygous black × white.
2. Suppose that in outer space there exist creatures whose traits are inherited by Mendel's laws. You find that purple eyes, *P*, are dominant to yellow eyes, *p*. Two purple-eyed creatures mate and produce six offspring. Four of them have purple eyes and two have yellow eyes. What are the genotypes of the parents? The phenotypes? What are the genotypes of the offspring?
3. In fruit flies, long wing, *L*, is dominant to short wing, *l*. Two long-wing flies produced 49 short-wing and 148 long-wing offspring. What were the probable genotypes of the parents? What proportion of the long-wing offspring should be heterozygous?
4. In humans, brown eyes, *B*, are dominant to blue eyes, *b*. A brown-eyed man marries a blue-eyed woman. They have eight children, all are brown-eyed. What are the possible genotypes of each person in the family?
5. In Andalusian fowl, *B* is the gene for black plumage. Small *b* is the gene for white plumage. The genes show incomplete dominance. The heterozygous condition results in blue plumage. List the genotypic and phenotypic ratios expected from the crosses (a) black × blue, (b) blue × blue, (c) blue × white.
6. In cattle, black coat color is dominant to white coat color. A farmer has a black male of undetermined genotype. How can the farmer determine the genotype of the male?
7. A black, smooth guinea pig was mated with an albino, rough guinea pig. Their offspring were black rough and black smooth. These were the only types produced over a period of years in a number of matings. Black and rough are dominant traits. What was the probable genotype of each parent?
8. What is the probable genotypic ratio among children born to a mother having the genotype $I^AI^O$ and a father with type AB?
9. One parent has type A blood and the other parent has type B blood. What are their genotypes if they produced a large number of children whose blood types were (a) all AB, (b) ½ AB and ½ B, (c) ½ AB and ½ A, and (d) ¼ AB, ¼ A, ¼ B, ¼ O?
10. A woman with blood type B has a child with blood type O. What are the genotypes of the mother and child? Which genotypes could the father not have?

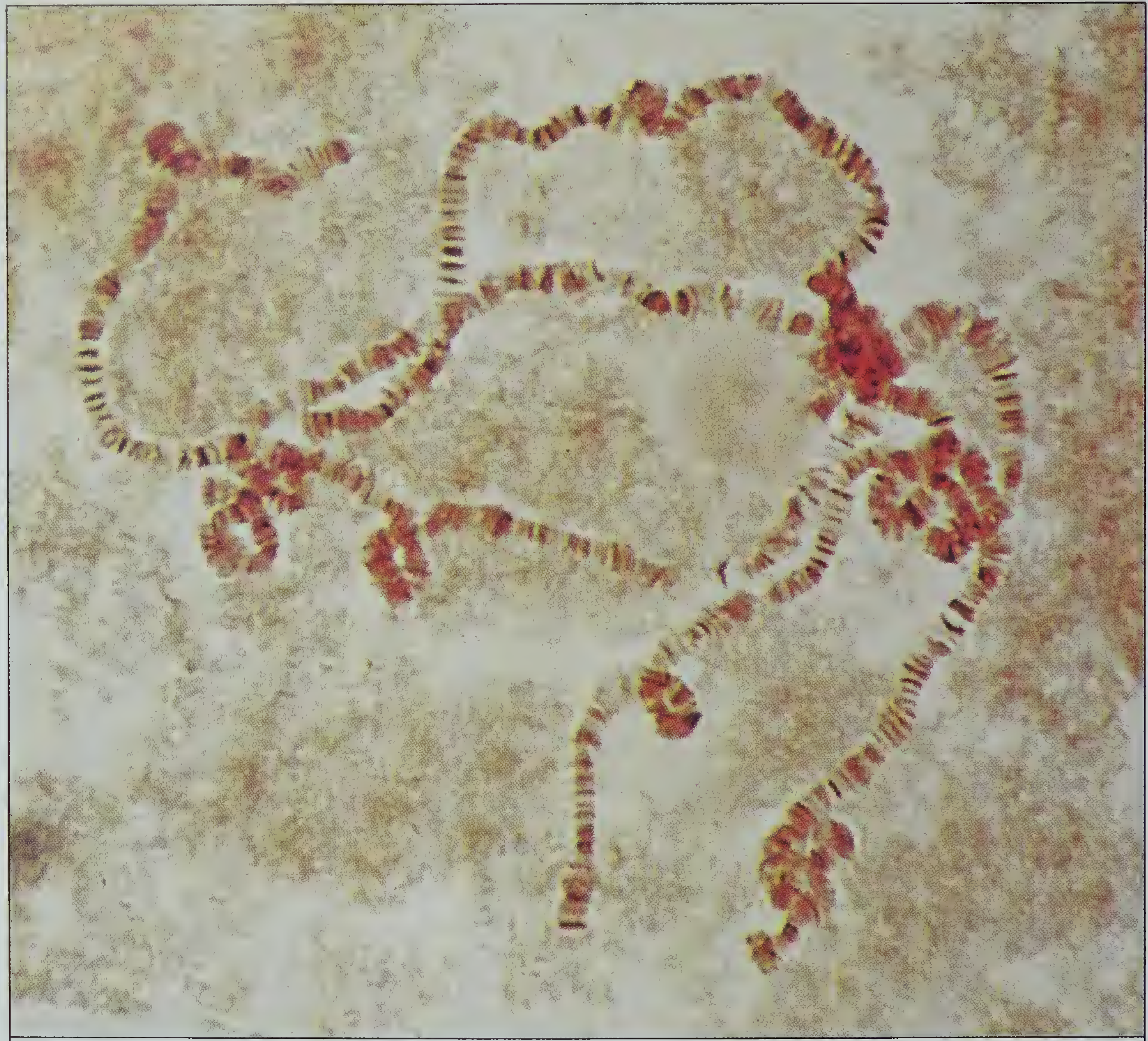
### EXTENDING YOUR IDEAS

1. An organism *AaBBCcDd* is crossed with an organism *AaBbCcDD*. Without working out the entire cross, find the expected frequency of an offspring with the genotype *aaBbCcDd*.
2. A plant is wanted which has the genotype *AAbb*. Given parental strains *AABB* and *aabb*, outline the methods you would use to obtain such a plant. How would you test the genotype of the plant once you think you have obtained it?
3. Radishes may be long, round, or oval. Crosses of long and oval gave 159 long and 156 oval. Crosses of oval and round produced 203 oval and 199 round. Crosses of long and round gave 576 oval. Explain.

### SUGGESTED READINGS

Bornstein, Jerry and Bornstein, Sandy, *What Is Genetics*? New York, Messner Pub., 1979.

Raab, Carl and Raab, Joan, *The Student Biologist Explores Genetics*. New York, Rosen Press, 1979.



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*Within each cell of your body are structures called chromosomes that contain thousands of genes. The genes of the Drosophila chromosome above are responsible for the development of specific fruit fly traits. How do genes control development of traits? What can happen if chromosomes are not replicated normally during cell division? How can abnormal genes and chromosomes be detected in humans?*

Chapter
8

# GENES AND CHROMOSOMES

**GOAL:** You will gain an understanding of how genes and their locations on chromosomes affect the phenotypes of humans and other organisms.

The early 1900's showed a burst of research in the field of genetics. Important observations seemed to link events of meiosis (Section 6:9) with some of Mendel's laws. It was noted that homologous chromosomes separate during gamete formation. A fertilized egg has both homologs of each chromosome pair (the diploid pair). It was reasoned that each cell that is formed from the zygote by mitosis has pairs of homologous chromosomes.

In the early 1900's, it was hypothesized that genes are located on chromosomes.

As a result of observations and reasoning, a hypothesis that genes are located on chromosomes was made. One gene for a trait is carried on one homolog and the other gene is on the other homolog. Later this hypothesis was verified.

## THE CHROMOSOME THEORY OF HEREDITY

### 8:1 Sex Determination

*Drosophila melanogaster* (droh SAHF uh luh • mel uh NOH gas tur), fruit flies, are often used in genetic studies. They are small (about 2 mm in length), easily handled, and they produce many offspring in two weeks.

In *Drosophila* cells, Thomas Hunt Morgan (1866-1945) first noted a difference in the chromosomes of females and males. Female flies have four pairs of homologous chromosomes, but males have three homologous pairs plus one pair of two different chromosomes (Figure 8-1). One of the two chromosomes looks like those of the fourth pair of female chromosomes. It is called the **X chromosome.** The other chromosome which has a different shape is called the **Y chromosome.** The female fruit fly has two X chromosomes while a male has one X and one Y chromosome.

**FIGURE 8-1.** Male and female *Drosophila* have eight chromosomes. Three pairs are autosomes. The other two chromosomes are sex chromosomes. Females have two X chromosomes. Males have one X and one Y.

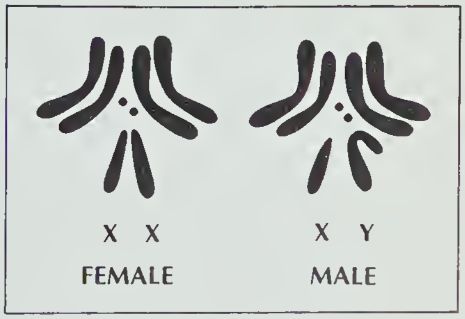
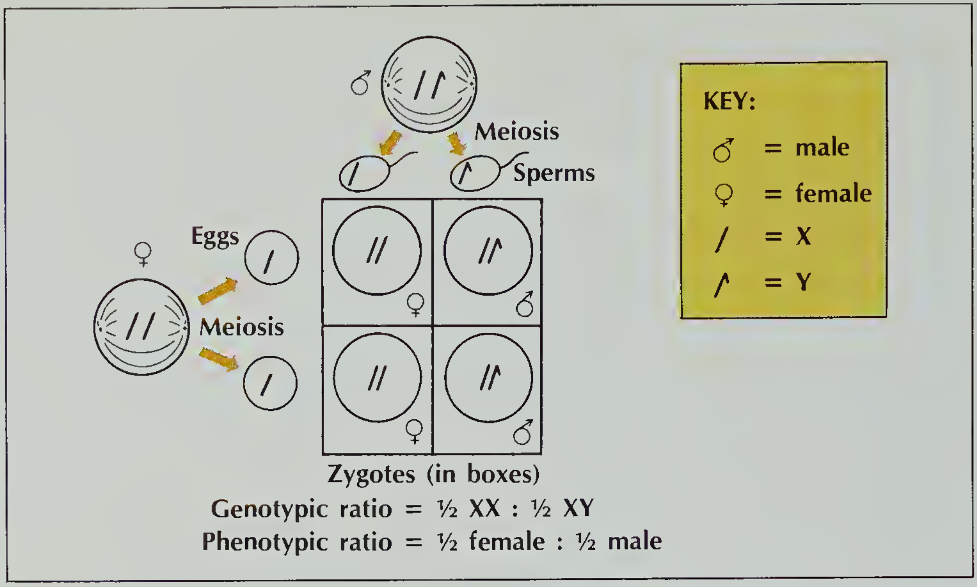


FIGURE 8-2. This Punnett square shows that half the possible offspring are female and half are male.



Because the X and Y chromosomes are related to sex, they are called **sex chromosomes.** The other chromosomes are called **autosomes** (AWT uh sohmz). Thus, both female and male *Drosophila* have three pairs of autosomes and one pair of sex chromosomes. A female normally has three pairs of autosomes and two X chromosomes. A male normally has three pairs of autosomes, an X chromosome, and a Y chromosome.

Cells of *Drosophila* have three pairs of autosomes and one pair of sex chromosomes. X and Y are the sex chromosomes.

All the gametes produced by the female will contain an X chromosome. The male fruit fly's X and Y chromosomes are not homologous, but they behave as a homologous pair during meiosis. They are separated from each other in gamete formation. Half the male's gametes will contain the X chromosome and half will contain the Y chromosome. The possible combinations of X and Y chromosomes among offspring can be determined like other traits (Figure 8-2). By probability, half the offspring would have the genotype XX (female). The other half would have XY (male).

By probability, half of the *Drosophila* offspring are male and half are female.

Such a pattern of sex determination is evident in many organisms, including humans. However, the pattern is different in some organisms. For example, in grasshoppers, there is no Y chromosome. Females have two X chromosomes; males have only one X chromosome.

## 8:2 Morgan's Discoveries

In 1910, Morgan made an unexpected discovery in the eye color trait of his fruit flies. He found a male with white eyes. These flies were from a pure line having only red eyes.

He decided to breed this white-eyed male to red-eyed females assuming that red eye color was dominant to white eye color. Morgan expected to find all red-eyed offspring in the $F_1$

generation. He also expected the $F_1$ flies, when interbred, to produce a ratio of three red-eyed flies to one white-eyed fly. He did get these results.

Morgan also noted that all the white-eyed flies in the $F_2$ generation were *males!* There were no white-eyed females. Because white eye color seemed to be linked with sex, it is called a **sex-linked characteristic.**

Morgan's hypothesis was that the alleles for eye color are carried only on the X chromosomes, and that there are no alleles for eye color on the Y chromosome. Thus, the parental cross was between red-eyed females ($X^RX^R$) and white-eyed males ($X^rY$) (Figure 8-3). X and Y represent the sex chromosomes. *R* represents the red eye color allele, and *r* stands for the white eye color allele. The results of the cross ($F_1$ generation) were red-eyed males ($X^RY$) and red-eyed females ($X^RX^r$). The $F_2$ generation (Figure 8-3) would have been red-eyed females ($X^RX^R$ or $X^RX^r$), red-eyed males ($X^RY$), and white-eyed males ($X^rY$). Morgan's hypothesis explained his previous data by showing how all males are white-eyed in the $F_2$ generation.

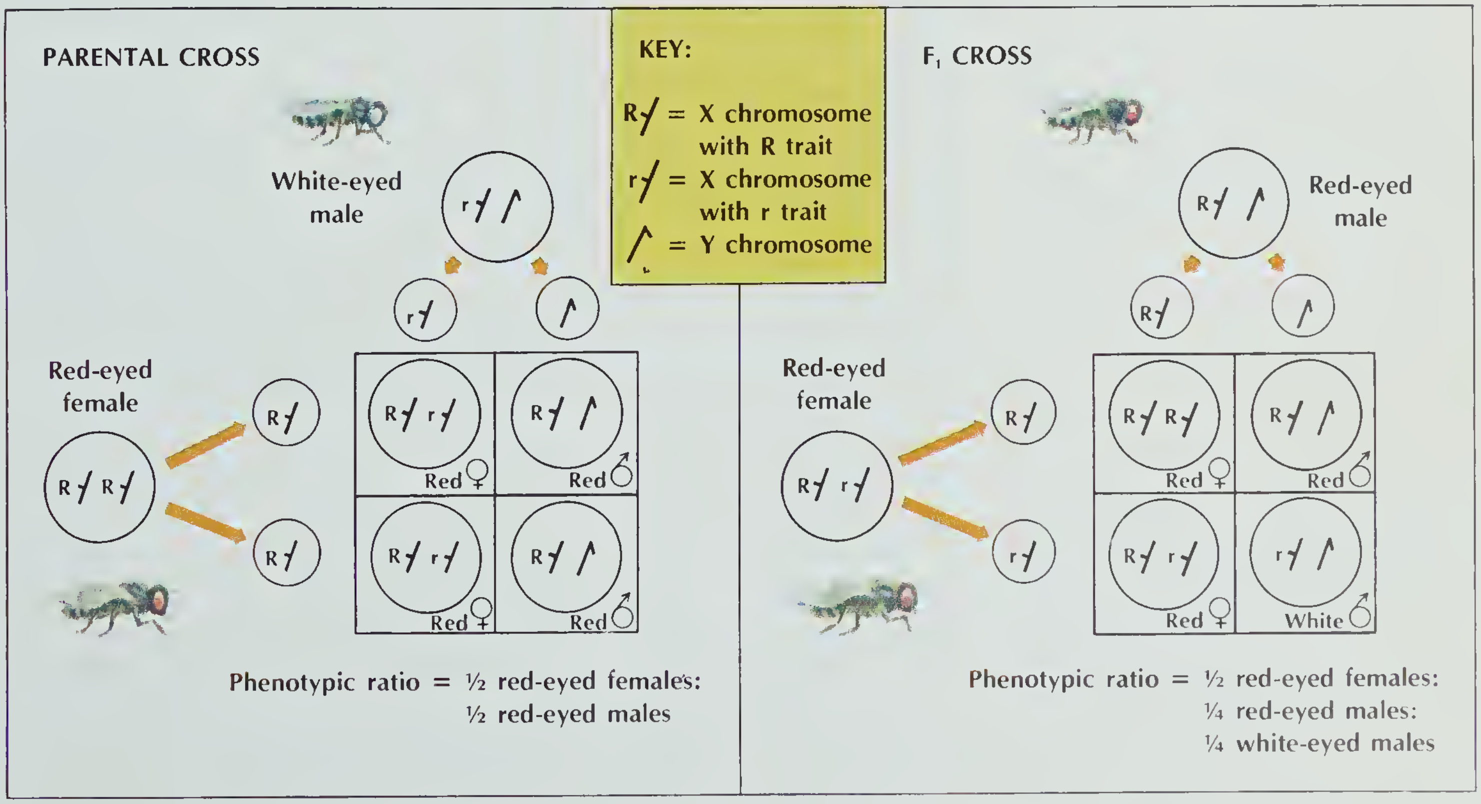
But, a hypothesis should predict new facts. Morgan predicted that he could produce white-eyed females by breeding an $F_1$ red-eyed female ($X^RX^r$) with a white-eyed male ($X^rY$). When such a cross was done, Morgan's prediction was confirmed. There were white-eyed females among the offspring. This evidence was also important in supporting the hypothesis that genes are carried on chromosomes.

All of Morgan's $F_2$ fruit flies with white eyes were males.

Traits inherited with sex are called sex-linked characteristics.

Morgan hypothesized that alleles for eye color in *Drosophila* are carried on the X chromosome but not on the Y chromosome.

**FIGURE 8-3. Assuming eye color is sex-linked, results predicted with Punnett squares agree with Morgan's experimental results. The parental and $F_1$ crosses he did are shown.**


PARENTAL CROSS
White-eyed male
r/ /\
r/
/\
Red-eyed female
R/ R/
R/
R/
R/ r/
Red ♀
R/ /\
Red ♂
R/ r/
Red ♀
R/ /\
Red ♂
Phenotypic ratio = ½ red-eyed females: ½ red-eyed males
KEY:
R/ = X chromosome with R trait
r/ = X chromosome with r trait
/\ = Y chromosome
F₁ CROSS
Red-eyed male
R/ /\
R/
/\
Red-eyed female
R/ r/
R/
r/
R/ R/
Red ♀
R/ /\
Red ♂
R/ r/
Red ♀
r/ /\
White ♂
Phenotypic ratio = ½ red-eyed females: ¼ red-eyed males: ¼ white-eyed males

## PEOPLE IN BIOLOGY

In 1970, in front of a small group of scientists gathered at the University of Wisconsin, Har Gobind Khorana announced that he and his research team had made the first synthetic gene. This announcement was the result of many years of research in chemical genetics.

(1922-   )

Har Gobind Khorana

Khorana was born and reared in India. After he earned his degrees at Punjab University, he moved to England where he began his life-long study of nucleic acids and proteins. From there his research led him to a post in Canada. Later he became Co-director of the Institute for Enzyme Research at the University of Wisconsin. It was here that Khorana began to decipher the genetic code of yeast. In 1968 he received the Nobel Prize for Medicine for interpreting the code and explaining how genes determine the function of cells. Only two years later, Khorana reported his synthesis of a yeast gene.

Dr. Khorana, who has been a United States citizen since 1966, now lives in Massachusetts with his wife. He has three children, and in his spare time he enjoys hiking, swimming, and listening to music.

## 8:3 Solving Problems

Problems with sex-linked traits can be solved in the same way you solve other genetics problems.

*Sample Problem 1:* In a certain animal, the gene for black coat color *(B)* is dominant to the gene for orange coat color *(b)*. The characteristic is sex-linked. Determine the probable genotypic and phenotypic ratios among the offspring produced by a heterozygous female and a black male.

*Solution:*

Include the alleles and the chromosomes in problems involving sex-linked traits.

(1) Write the genotype of each parent.

female: $X^BX^b$

male: $X^BY$

Consider each chromosome and its allele as a unit.

(2) Determine the probable distribution of chromosomes and alleles in the gametes.

female = $X^BX^b \rightarrow \frac{1}{2}\ X^B + \frac{1}{2}\ X^b$

male = $X^BY \rightarrow \frac{1}{2}\ X^B + \frac{1}{2}\ Y$

(3) Using the product rule, multiply to find the possible combination of chromosomes and alleles (genotypic ratio).

$$\begin{array}{r} \frac{1}{2}\ X^B + \frac{1}{2}\ X^b \\ \times\ \frac{1}{2}\ X^B + \frac{1}{2}\ Y \\ \hline \frac{1}{4}\ X^BX^B + \frac{1}{4}\ X^BX^b + \frac{1}{4}\ X^BY + \frac{1}{4}\ X^bY \end{array}$$

(4) Interpret the genotypes to find the phenotypic ratio.

$\frac{1}{4}\ X^BX^B$ = black female $\frac{1}{4}\ X^BY$ = black male
$\frac{1}{4}\ X^BX^b$ = black female $\frac{1}{4}\ X^bY$ = orange male

Therefore, the phenotypic ratio is ½ black females : ¼ black males : ¼ orange males.

The Punnett square answer to Sample Problem 1 is shown in Figure 8-4.

*Sample Problem 2:* What genotypes and phenotypes must each parent have to produce an orange female?

*Solution:* The genotype of the orange female must be $X^bX^b$ because the gene for orange is recessive. One of the X chromosomes is received from the mother. The other is received from the father. Therefore, the father's genotype must be $X^bY$. He is orange. The mother must have the genotype $X^BX^b$ (black) or $X^bX^b$ (orange).

## 8:4 Nondisjunction

Calvin Bridges (1889-1938) made another unexpected discovery working with fruit flies. He found female flies which had two X chromosomes and a Y chromosome. Also, some male flies had just an X chromosome and no Y chromosome at all. These unusual patterns occurred because the homologous sex chromosomes of the parents failed to segregate properly during meiosis (Figure 8-5). He called this process **nondisjunction** (nahn dihs JUNK shun). Nondisjunction of autosomes can also occur. Bridges' discovery of nondisjunction was associated with abnormal genetic results and was important evidence of the **chromosome theory of heredity:** *genes are located on chromosomes.*

Bridges' discovery of nondisjunction changed the concept of sex determination. It had been thought that the presence of the Y chromosome in fruit flies determined sex. Bridges found that in *Drosophila* the chromosome arrangement XXY will produce a female and a single X will produce a male. Thus, it is now known that the presence of *two* X chromosomes produces females and the absence of the second X chromosome produces males. Sex in fruit flies is determined by the number of X's.

In humans, unlike fruit flies, the Y chromosome determines sex. If a Y chromosome is present, a male will be produced no matter how many X chromosomes there are. Cells such as X,

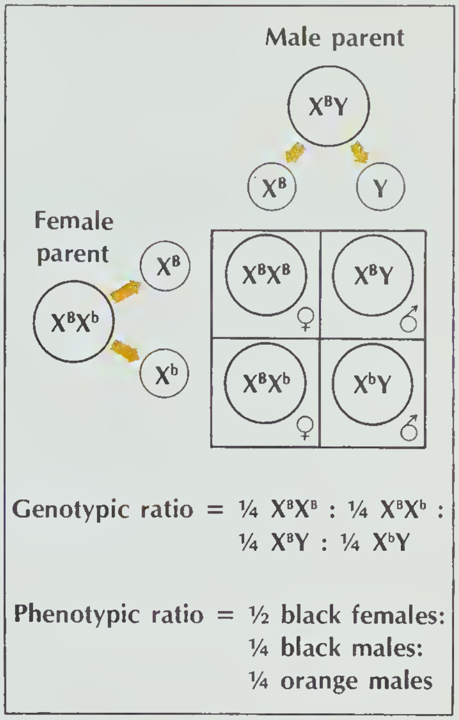
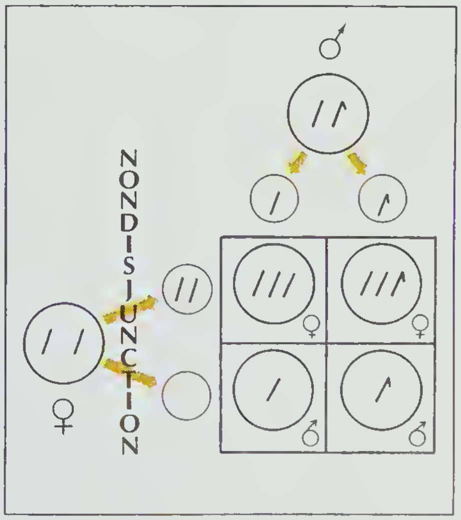

Male parent
$X^BY$
$X^B$
Y
Female parent
$X^BX^b$
$X^B$
$X^b$
$X^BX^B$ ♀
$X^BY$ ♂
$X^BX^b$ ♀
$X^bY$ ♂
Genotypic ratio = ¼ $X^BX^B$ : ¼ $X^BX^b$ : ¼ $X^BY$ : ¼ $X^bY$
Phenotypic ratio = ½ black females: ¼ black males: ¼ orange males

**FIGURE 8-4. The Punnett square solution to Sample Problem 1 shows the inheritance of coat color which, in this example, is sex-linked.**

**FIGURE 8-5. Nondisjunction, failure of homologous chromosomes to segregate properly, explains the rare occurrence of white-eyed females and red-eyed males in *Drosophila*.**



XX, and XXX produce females while combinations such as XY, XXY, and XXXY produce males.

The human Y chromosome seems to carry genes for male sex. The Y chromosomes also carry other genetic information. Some Y chromosome genes do not have corresponding genes on the X chromosome. For example, the gene which causes the rims of the ears to be hairy is on the Y chromosome only.

Some genes are carried on the Y chromosome, but not the X chromosome.

### REVIEWING YOUR IDEAS

1. Why are *Drosophila* useful for genetic studies?
2. Describe the chromosomes of male and female *Drosophila*.
3. Why are the chances of a couple having a girl 50:50?
4. What was unusual about Morgan's $F_2$ 3:1 ratio?
5. What is nondisjunction?

# OTHER GENETICS CONCEPTS

## 8:5 Gene Linkage

Many genes are located on a single chromosome.

Today it is known that the total number of genes in a cell is much greater than the total number of chromosomes. Thus, each chromosome must contain many different genes. Each gene influences certain traits. Genes which occur on the same chromosome are said to be linked. This phenomenon is called **gene linkage.**

Think of the cross of tall, red-flowered plants, *TTRR*, and short, white-flowered plants, *ttrr*. A 9:3:3:1 ratio occurs in the $F_2$ generation (Figure 7-13). The expected results would be different if the genes were linked (Figure 8-6).

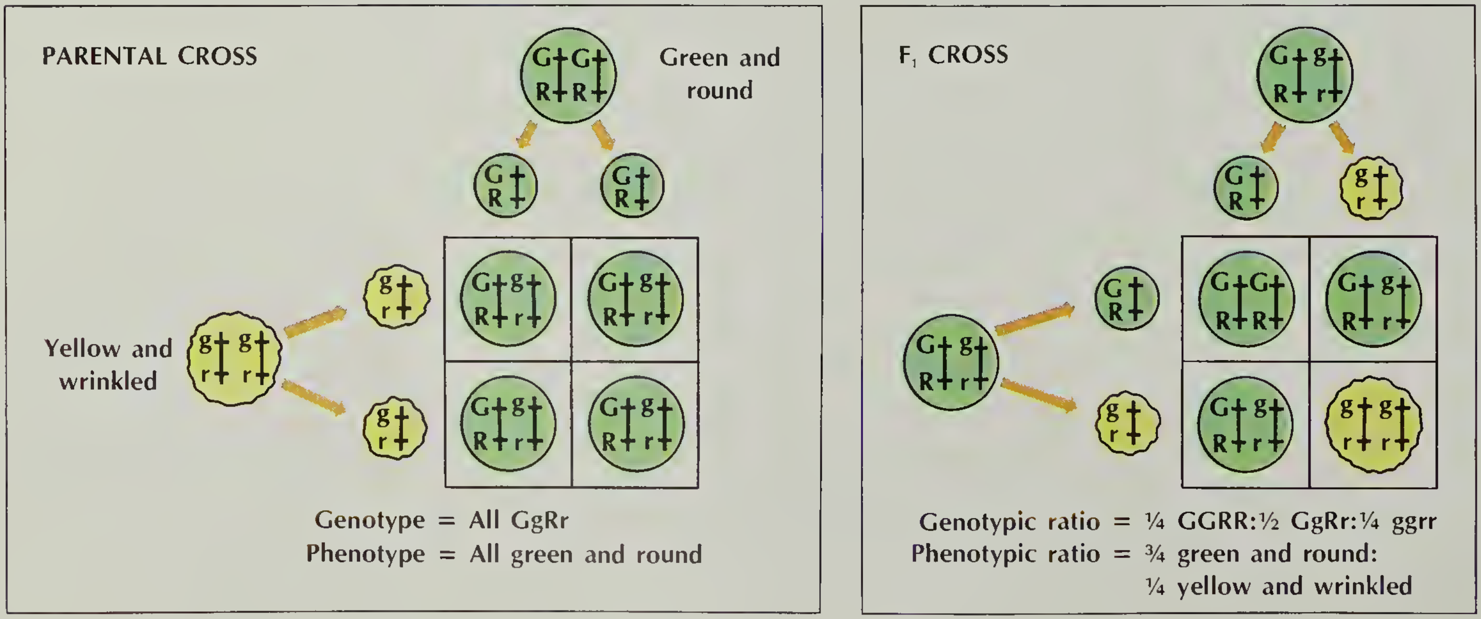

PARENTAL CROSS
Green and round
Yellow and wrinkled
GG RR
G R
G R
gg rr
g r
g r
Gg Rr
Gg Rr
Gg Rr
Gg Rr
Genotype = All GgRr
Phenotype = All green and round
$F_1$ CROSS
Gg Rr
G R
g r
Gg Rr
G R
g r
GG RR
Gg Rr
Gg Rr
gg rr
Genotypic ratio = ¼ GGRR:½ GgRr:¼ ggrr
Phenotypic ratio = ¾ green and round:
¼ yellow and wrinkled

**FIGURE 8-6. The Punnett square results involving two traits that are linked show that linked genes do not assort independently.**

Assume in a certain plant that green seeds, *G*, are dominant to yellow seeds, *g*, and that round seeds, *R*, are dominant to wrinkled seeds, *r*. Also assume that the alleles are on the same pair of homologous chromosomes. As a result, they do not assort independently (Section 7:9) during meiosis. They stay together and enter the gametes in the same combinations each generation.

If genes are linked, they do not assort independently.

When *GGRR* and *ggrr* are crossed, the $F_1$ offspring have green, round seeds *(GgRr)*. These results are the same as those produced when genes are not linked. But, there are only three possible genotypes among the $F_2$ offspring—*GGRR*, *GgRr*, and *ggrr*. The phenotypic ratio is three green, round to one yellow, wrinkled. Without gene linkage, the $F_2$ phenotypic ratio is 9:3:3:1 because of independent assortment. *Thus, gene linkage reduces the chances for genetic recombination and variety among offspring.*

Gene linkage reduces variety among offspring.

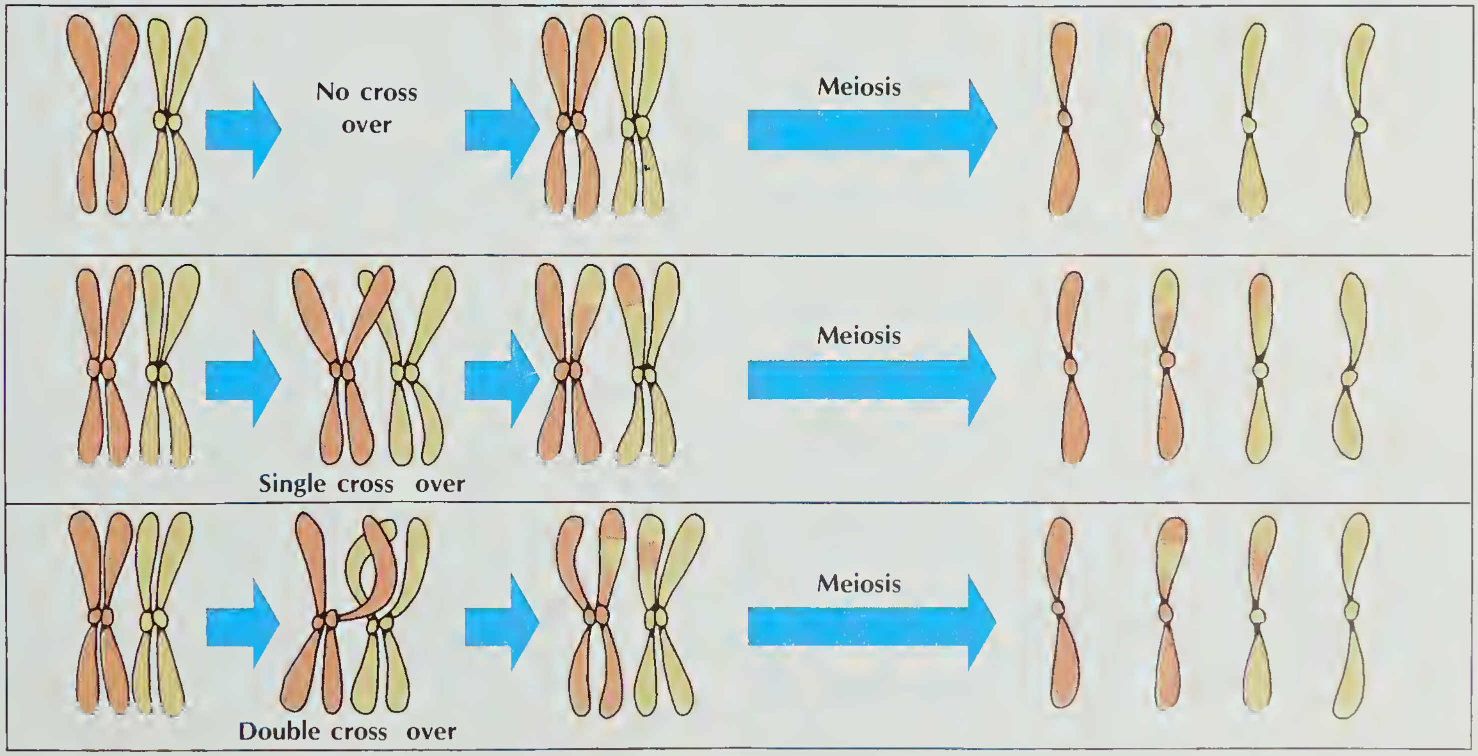
## 8:6 Crossing-Over

Suppose all linked genes in a population remained in their parental combinations. The variety among organisms would be reduced. Geneticists have come to realize that linked genes can be separated by crossing-over. **Crossing-over** is an exchange of segments of chromosomes between two homologous chromatids (Figure 8-7). Crossing-over may occur at more than one place along a chromosome.

Crossing-over, exchange of alleles between homologous chromosomes, separates linked genes.

Crossing-over occurs during prophase I of meiosis and may continue into metaphase I (Section 6:10). When homologous chromosomes pair, the four chromatids lie side by side. They are

FIGURE 8-7. The differences in the genetic makeup of gametes produced with no cross-over, a single cross-over, and a double cross-over can be easily compared.



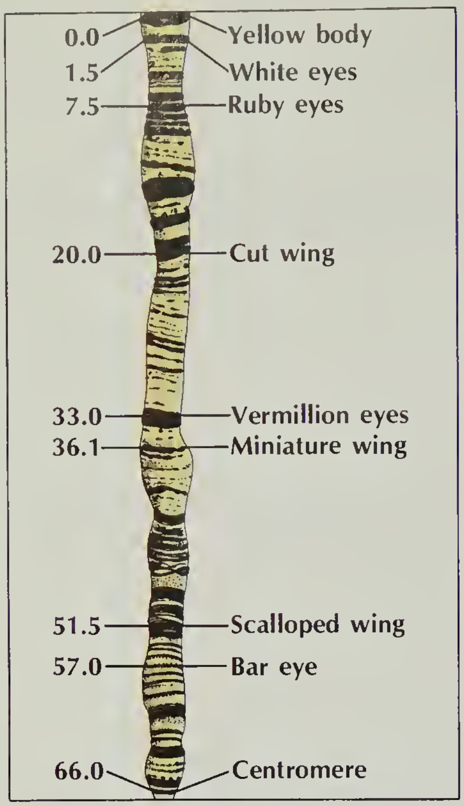

0.0
Yellow body
1.5
White eyes
7.5
Ruby eyes
20.0
Cut wing
33.0
Vermillion eyes
36.1
Miniature wing
51.5
Scalloped wing
57.0
Bar eye
66.0
Centromere

**FIGURE 8-8. A genetic map of the *Drosophila* X chromosome shows the linear arrangement of genes. Many of the genes that have been mapped were omitted from this drawing for simplification.The numbers indicate relative distances between genes.**

Frequency of crossing-over is an indication of the distance between genes on a given chromosome.

positioned so that alleles of one chromosome are beside alleles for the same trait on the other chromosome. When the homologous pairs are pulled apart in meiosis I, the chromatids can have different combinations of genes as a result of exchange.

Crossing-over has survival value for a population. Most gametes will have the parental combination of linked genes, but some are different as a result of crossing-over. These gametes are called **recombination gametes.** The union of these gametes with other gametes results in offspring with a wider variety of traits which helps a population survive over long periods of time in a changing environment. These traits could be important if changes in the environment favored new features (Section 6:13).

Crossing-over can be used as a tool to learn the location of genes on chromosomes. When genes are known to be linked, expected phenotypic ratios can be determined. Variations from the expected ratios show how often two genes on homologous chromosomes cross-over. The frequency or amount of cross-over can then be used to determine where the genes are on the chromosomes.

The linear arrangement of genes on chromosomes has been worked out for many oganisms. The location of genes on a chromosome is called a **genetic map.** The genetic map is determined by the amount of crossing-over between different genes. The farther apart two genes are, the greater the chance of their crossing-over. Why?

As an example, it was determined that in *Drosophila* the ruby-eye gene was farther from the bar-eye gene than it was from the cut-wing gene (Figure 8-8). More crossing-over occurred between the ruby-eye and bar-eye than between the ruby-eye and cut-wing genes. The distances between the genes are given in genetic map units, shown as numbers on Figure 8-8. Genetic map units indicate the amount of crossing-over between genes. One unit equals 1% crossing-over. Why is it important to learn where genes are on chromosomes? What are the advantages of making genetic maps of human chromosomes?

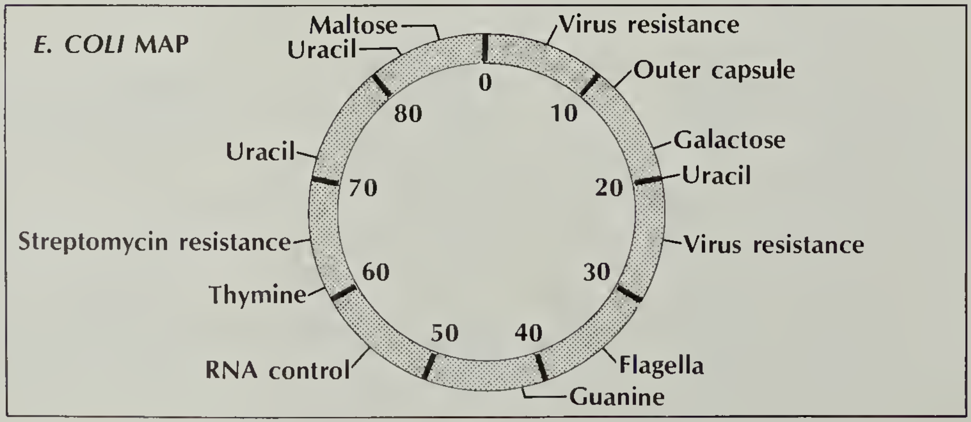

E. COLI MAP
Maltose
Uracil
Virus resistance
Outer capsule
0
10
20
30
40
50
60
70
80
Galactose
Uracil
Virus resistance
Flagella
Guanine
RNA control
Thymine
Streptomycin resistance
Uracil

**FIGURE 8-9. Chromosomes in bacteria are circular. This genetic map of the *E. coli* chromosome, a bacterial chromosome, shows some of the genes whose locations are known. Many genes were omitted from this drawing for simplification.**

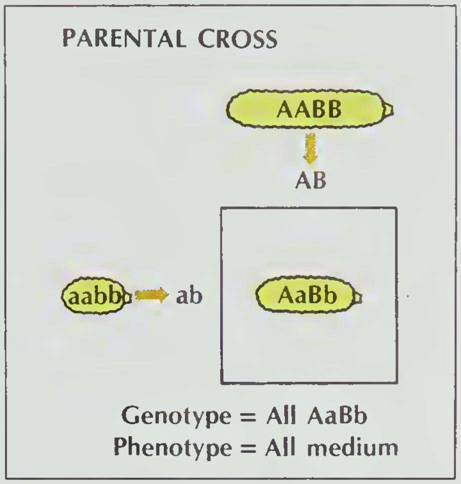
## 8:7 Many Genes—One Effect

The hereditary traits studied so far are explained by Mendel's laws in which single pairs of genes operate by complete or incomplete dominance (Section 7:8). Examples are red flowers or white flowers, normal color vision or color blindness, and round seeds or wrinkled seeds. They are determined by the combination of two alleles on a single pair of chromosomes.

However, Mendel's laws do not explain all genetic traits. For example, there is a wide range of ear lengths in corn. Ears of corn are not just long or short. Long and short are limits between which many lengths exist. If length were controlled by a single pair of genes showing incomplete dominance, there would be only three lengths—long, medium, and short.

Many ear lengths in corn is an example of **continuous variation.** Continuous variation can be explained by assuming that more than one pair of genes is involved. Suppose that two pairs of genes (*A* and *a*, *B* and *b*) are responsible, and they are on different pairs of homologs. Suppose also that *AABB* represents the genotype of the longest ears of corn, and *aabb* represents the genotype of the shortest ears of corn. A cross between *AABB* and *aabb* parents results in $F_1$ offspring which are *AaBb* (intermediate length) (Figure 8-10).

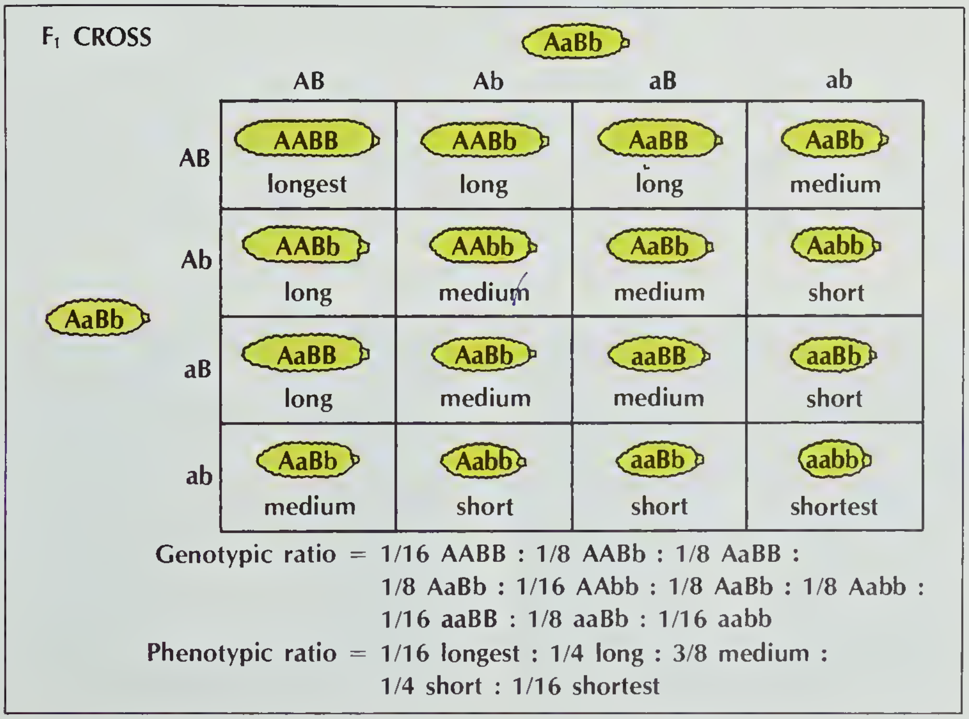
If these $F_1$ organisms are interbred, a broad range of genotypes and phenotypes is produced in the $F_2$ offspring (Figure 8-11). The genotype *AaBb*, medium length ears of corn, is the one most often produced. *AABB* (longest) and *aabb* (shortest) are very seldom produced. The rest of the genotypes produce the other lengths.



Genotype = All AaBb
Phenotype = All medium

**FIGURE 8-10. This Punnett square shows a parental cross of corn in which two pairs of genes determine one trait, ear length.**

The range of phenotypes seen in continuous variation is controlled by several pairs of genes.



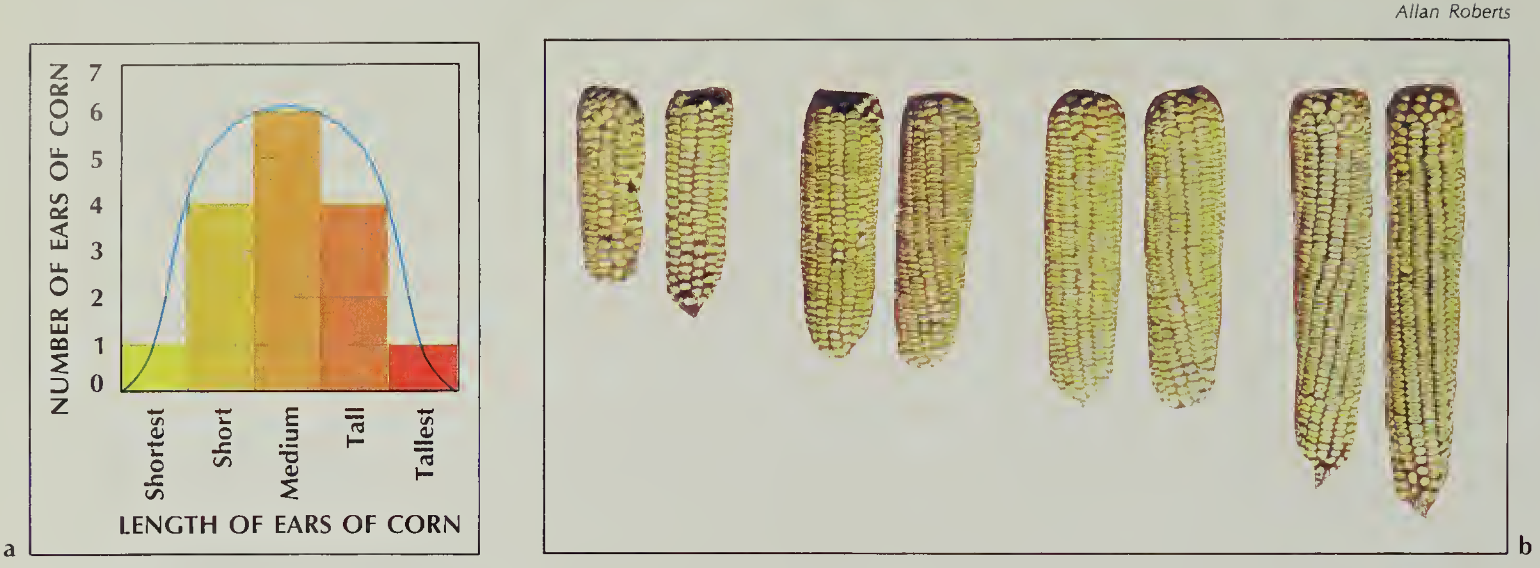
$F_1$ CROSS

| AaBb × AaBb | AB | Ab | aB | ab |
|---|---|---|---|---|
| AB | AABB<br>longest | AABb<br>long | AaBB<br>long | AaBb<br>medium |
| Ab | AABb<br>long | AAbb<br>medium | AaBb<br>medium | Aabb<br>short |
| aB | AaBB<br>long | AaBb<br>medium | aaBB<br>medium | aaBb<br>short |
| ab | AaBb<br>medium | Aabb<br>short | aaBb<br>short | aabb<br>shortest |

Genotypic ratio = 1/16 AABB : 1/8 AABb : 1/8 AaBB :
1/8 AaBb : 1/16 AAbb : 1/8 AaBb : 1/8 Aabb :
1/16 aaBB : 1/8 aaBb : 1/16 aabb

Phenotypic ratio = 1/16 longest : 1/4 long : 3/8 medium :
1/4 short : 1/16 shortest

**FIGURE 8-11.** When two pairs of genes determine a trait, many different phenotypes (continuous variation) are possible in the $F_2$ generation.



Allan Roberts

**FIGURE 8-12. (a) A graph of the distribution of ear lengths in corn shows continuous variation. The distribution is bell-shaped with medium length ears occurring most often. (b) The continuous variation in length can be seen in the corn ears.**

Continuous variation is determined by multiple genes.

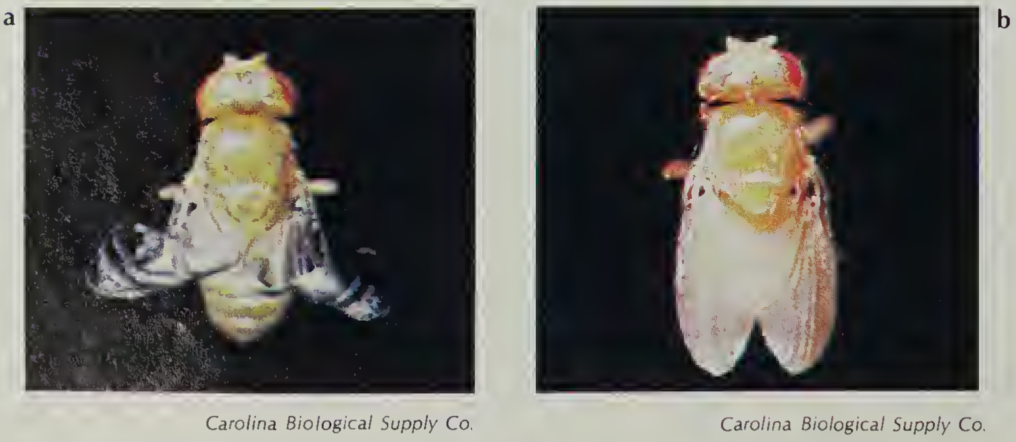
Some are longer than medium; some are shorter than medium. When graphed, these results show a distribution such as that in Figure 8-12. When these crosses are made, the results agree with those predicted by the Punnett square. Geneticists explain many such traits in terms of **multiple genes** or **multiple factors** in which many genes may affect a single trait. Human skin color is among other traits thought to be determined by multiple genes.

## 8:8 Heredity and Environment

Expression of genes may depend on environment.

Genes are the carriers of hereditary information. But, will the same genes produce the same features under all conditions? The answer is often no. In most cases, the expression of a gene depends on the environment in which the organism is developing. For example, a person might have genes for brown hair, but exposure to the sun might turn the hair blond.

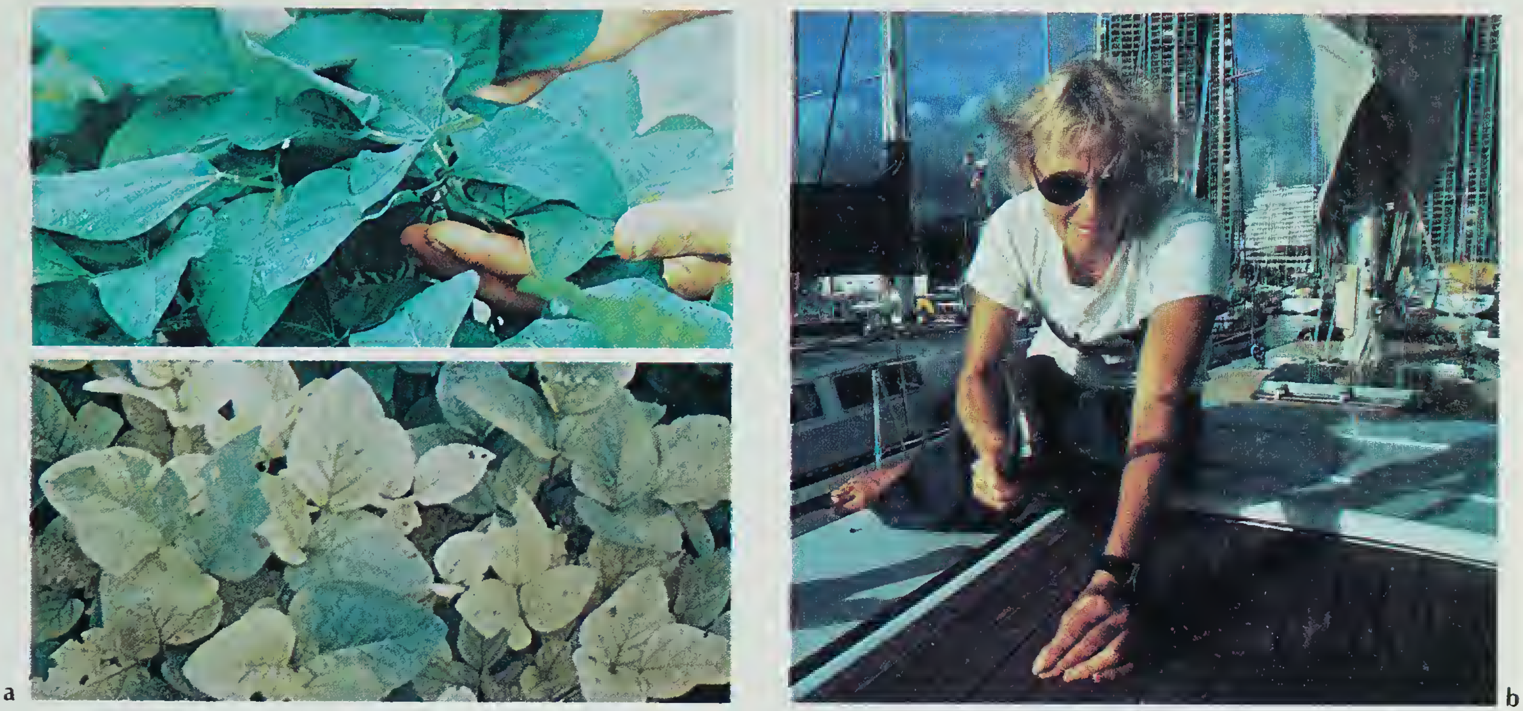
In fruit flies, the gene for curly wings is expressed differently at different temperatures. Curly-winged flies bred at 25°C will have offspring with curly wings. But at 16°C, the offspring will have straight wings. Both sets of offspring, if interbred at 25°C, will produce curly-winged flies.



Carolina Biological Supply Co.

Carolina Biological Supply Co.

**FIGURE 8-13. (a) Curly-winged *Drosophila* bred at 16°C will produce (b) straight-winged offspring. Temperature is an environmental factor that influences the final traits of this organism.**



USDA

USDA

Steve Lissau

**FIGURE 8-14. Environmental factors influence traits in many ways. (a) A soybean plant with ample iron (above) grows much better than an iron-deficient soybean plant (below). (b) Sun exposure can darken skin color and lighten hair color.**

One way of determining the effects of environment on traits is to study identical twins. Identical twins have exactly the same genotype because they are produced as a result of the dividing of one zygote. Identical twins separated at birth and raised in *different* environments usually have some different traits such as height, weight, and even intelligence. Thus, different environments can cause different expressions of the genotype. How might environment affect intelligence?

In general, the development of any organism is affected by the environment. A given genotype may be for long ears of corn. But, the soil in which the corn is growing may be poor, or there may be a drought during the growing season. Each of these may affect the phenotype so that there may be short ears of corn or even no ears. The phenotype depends on the environment as the source of needed materials and energy. An organism which cannot get the proper energy and materials will not develop properly no matter what its genetic message.

Environment may affect phenotypes.

## REVIEWING YOUR IDEAS

6. What is gene linkage?
7. Why does each chromosome contain many genes?
8. How does gene linkage affect variety among offspring? Why?
9. What is crossing-over? How does it affect variety among offspring?
10. How is crossing-over useful in constructing genetic maps?
11. What is continuous variation? How is it explained?
12. How are heredity and environment related?

# HUMAN GENETIC DISEASE

Genetic disease affects many humans in a variety of ways.

Humans inherit traits in the same manner as other organisms. In some cases, humans develop diseases which are genetic in origin. Genetic disease is not really rare; many people are affected by genetic diseases. It is estimated that in the United States, genetic disease is the cause of about 40% of all miscarriages and 40% of all infant deaths. It is also thought about 80% of all mentally retarded people and about ⅓ of all children that are in hospitals have problems that are genetic in origin. You can see why there is great concern about the prevention and treatment of genetic disease.

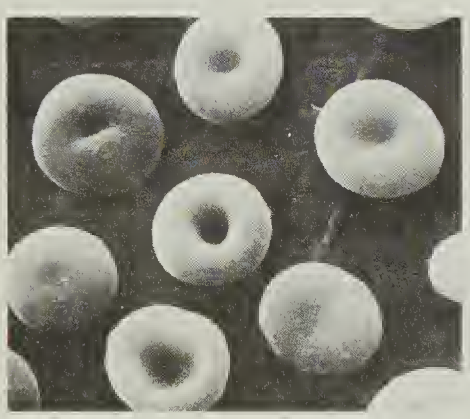
Genetic counseling can help couples weigh the risks of having children.

**Genetic counseling** is now available to prospective parents such as those from families with a history of hereditary disease. In counseling sessions, genetic counselors discuss with the couples their chances of having children with certain genetic diseases. The counselors may discuss results of tests with the prospective parents. They also help the couples make decisions about having children in situations where children with serious genetic defects are likely. As a result of genetic counseling, some couples may choose not to have children.

Some genetic diseases are caused by the presence of certain alleles. Others may result from an abnormal inheritance of chromosomes. Examples of both of these types of genetic disease are given here.

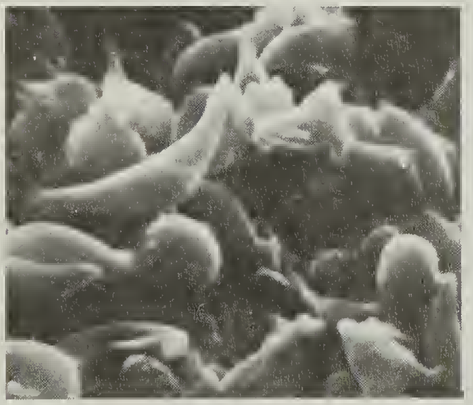
**FIGURE 8-15. (a) Normal red blood cells are disc-shaped. (b) Red blood cells of a person with sickle-cell anemia are distorted sickle shapes. These cells are shown magnified about 2200 times.**

a



*Kessel/Shih, Springer-Verlag ©1976*

b



*SEM Laboratory, Morris Brown College*

## 8:9 Problem-Causing Genes

Genes may exist in two or more forms or alleles. It is possible that one allele for a particular trait may be harmful or even lethal. A **lethal gene** causes death. It is estimated that every person has five to eight dangerous genes. Yet, most people show no signs of disease. Usually the harmful alleles are recessive, and their effects are masked by dominant alleles. When a person is homozygous for the recessive allele for a disease, the symptoms appear. Some examples of human diseases due to gene defects are discussed below.

- **Sickle-Cell Anemia.** This disease affects mostly black people. A person with the disease most often is homozygous recessive for a gene which makes hemoglobin. Hemoglobin is a protein in red blood cells which combines with oxygen and transports it to the cells. In persons with sickle-cell anemia, hemoglobin is abnormal, and the red cells are a sickled shape (Figure 8-15). Normal red cells are disc-shaped. Analysis shows that normal and abnormal hemoglobin differ in only one of the nearly six hundred amino acids that make up the molecule.

Doug Martin

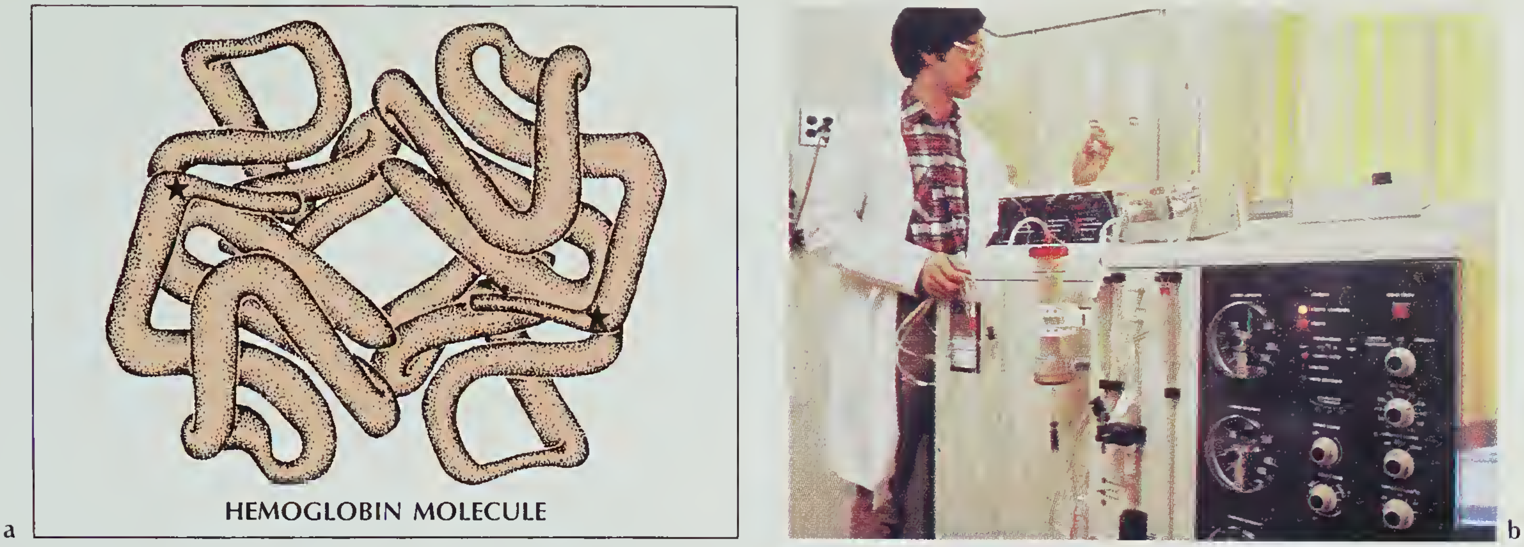


**FIGURE 8-16.** (a) Sickle-cell hemoglobin differs from normal hemoglobin by only one amino acid—valine appears instead of glutamine. A representation of hemoglobin is shown with the stars marking the locations of the sickle mutations. (b) A new machine, similar to a kidney machine, is being used successfully to treat sickle-cell patients.

This slight difference prevents abnormal hemoglobin from carrying enough oxygen to cells. The red cells change to a sickled-shape in the blood vessels. Because capillaries are of small diameter, the sickled cells do not easily pass through. The sickled cells clog the vessels. Thus, body cells do not get needed oxygen. As a result, the person might die.

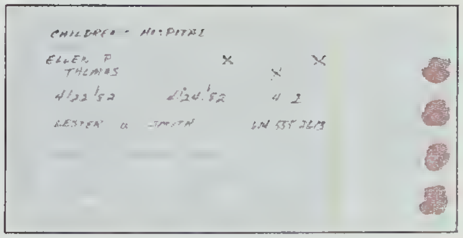
Sickled cells carry less oxygen and can block small blood vessels.

Several promising treatments of sickle-cell anemia are being used. Different chemicals are being used that, among other things, help hemoglobin to hold more oxygen. Many sickled red cells will return to their normal shape when carrying a lot of oxygen.

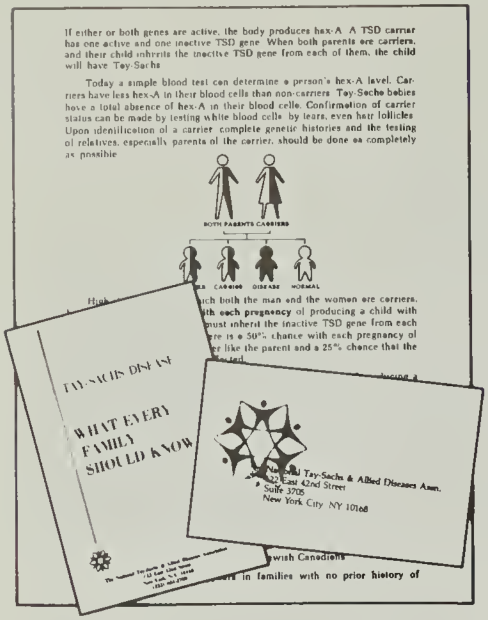
A blood test can be used to determine whether parents are carriers of genes for sickle cell. Carriers are heterozygotes; they have one gene for the sickled-cell trait. If both parents are carriers, they might choose not to have children.

- **Galactosemia** (guh lak tuh SEE mee uh). People who have this disease have two recessive genes for this trait. They cannot manufacture a certain enzyme. The enzyme is necessary for metabolism of a simple sugar, galactose. Galactose is part of lactose, a sugar found in milk. The galactose cannot be converted to glucose because the needed enzyme is missing. The galactose instead is converted to another compound. As that compound builds up, damage to the nervous system results. The damage can lead to an early death. Fortunately, the problems can be avoided by early detection and by a diet which contains no galactose.
- **PKU.** The dangerous recessive allele which causes this rare disease is carried by about one in every hundred thousand persons. PKU results from a missing enzyme and leads to severe mental retardation. An abnormal compound can be found by testing the urine of an infant and thus, the disease can be detected. Symptoms of PKU are prevented by a special diet early in life.

**FIGURE 8-17.** Most states now screen newborn babies for PKU as well as other diseases. Blood taken from the heel and collected on a card like this one is tested. If a positive test for PKU results, the baby can be treated with a special diet.



Lightforce



If either or both genes are active, the body produces hex-A. A TSD carrier has one active and one inactive TSD gene. When both parents are carriers, and their child inherits the inactive TSD gene from each of them, the child will have Tay-Sachs.

Today a simple blood test can determine a person's hex-A level. Carriers have less hex-A in their blood cells than non-carriers. Tay-Sachs babies have a total absence of hex-A in their blood cells. Confirmation of carrier status can be made by testing white blood cells, by tears, even hair follicles. Upon identification of a carrier, complete genetic histories and the testing of relatives, especially parents of the carrier, should be done as completely as possible.

ich both the man and the woman are carriers.
ith each pregnancy of producing a child with
must inherit the inactive TSD gene from each
ere is a 50% chance with each pregnancy of
er like the parent and a 25% chance that the

TAY-SACHS DISEASE

WHAT EVERY
FAMILY
SHOULD KNOW

National Tay-Sachs & Allied Diseases Assn.
122 East 42nd Street
Suite 3705
New York City NY 10168

wish Canadians
in families with no prior history of

FIGURE 8-18. Information about Tay-Sachs disease is available from the National Tay-Sachs & Allied Disease Association.

Diabetes may be caused by both genetic and environmental factors.

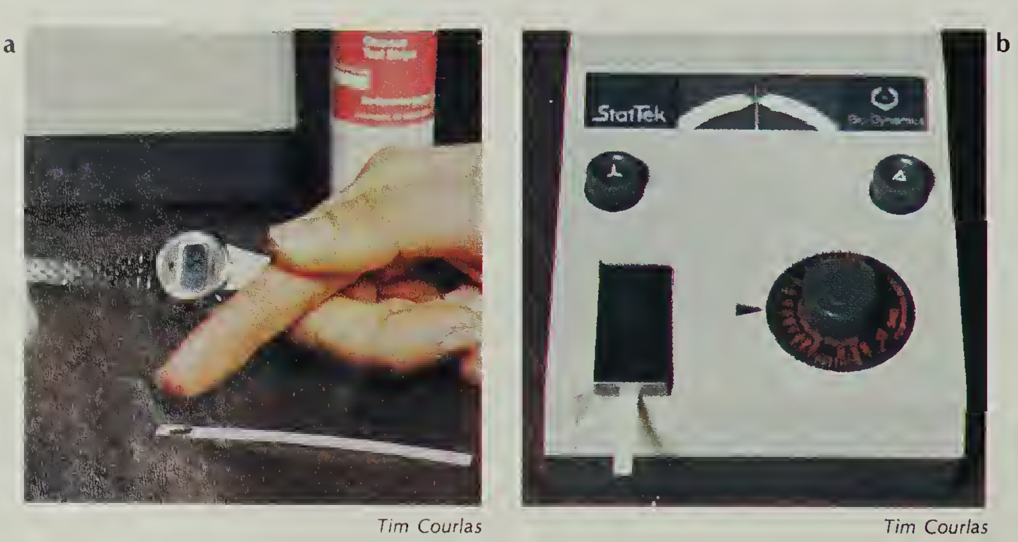
• **Tay-Sachs** (TAY saks) **Disease.** This disease occurs most often in Jewish people and is caused by a recessive gene. A child with this disease begins life normally, but the nervous system fails to develop properly. An important enzyme is missing that breaks down a kind of fat. The child loses ability to move normally, eventually becoming inactive. Death usually occurs by the age of two or three.

There is no cure for Tay-Sachs disease. However, parents in the high-risk group can have a blood test to determine whether they carry the allele. It is then their decision whether to have children. Blood tests can also be done on fetuses to see if they have Tay-Sachs.

What would be the chances of producing a child with Tay-Sachs disease if both parents were heterozygous? What if one parent were heterozygous and the other homozygous dominant?

• **Diabetes Mellitus** (MEL ut us). This disease is believed to be caused by several recessive genes. Factors such as age, weight, diet, and environment also influence the time of onset of the disease. Some persons with diabetes cannot produce enough insulin, the substance necessary for the transfer of sugar. As a result, sugar collects in the blood. Not enough sugar gets into the cells where it can be used as an energy source. Complications such as blindness, kidney disease, and heart disease may develop. There is no cure for the disease, but many people are treated by injections of insulin.

Diabetics find that by monitoring the level of sugar in the blood, the sugar level can more easily be kept within the normal range. If the blood sugar level is very high, the kidneys remove the excess sugar and it appears in the urine. When blood sugar is monitored, high sugar levels can be remedied before the kidneys overwork in removing the excess sugar. A diabetic determining that his or her blood sugar level is high would immediately take some insulin. Low sugar levels can also be determined, and in those cases, the diabetic would immediately eat something to raise the blood sugar level to normal.



Tim Courlas

Tim Courlas

FIGURE 8-19. Diabetics can monitor their own blood sugar level by (a) putting a small amount of blood on a special chemical-treated strip which (b) is read in a glucose determinator. The glucose value for this sample is 146 mg/dL.

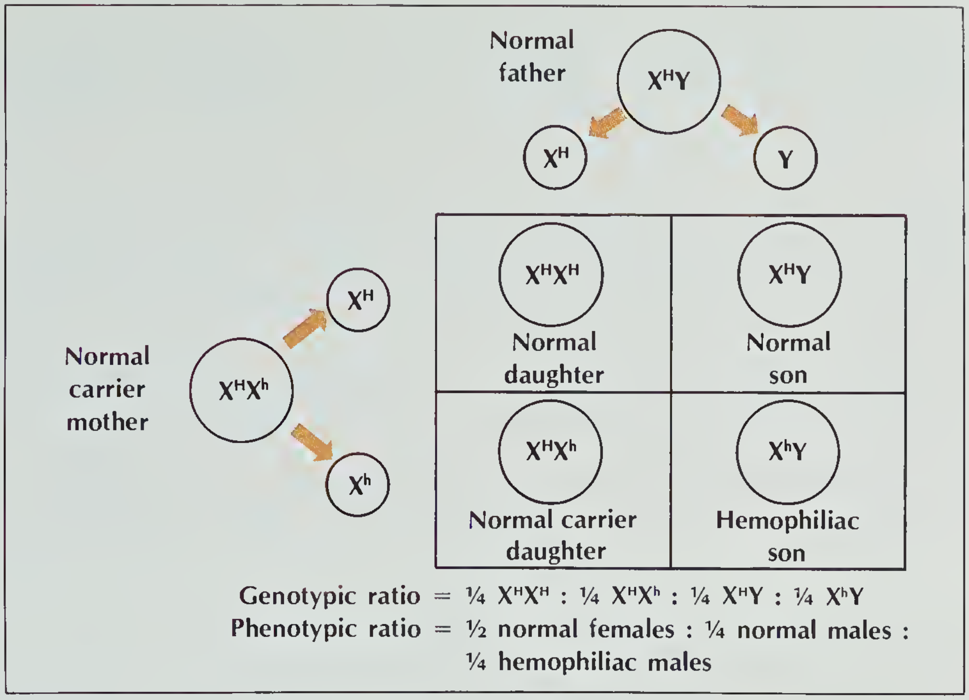

Normal father
$X^HY$
$X^H$
$Y$
Normal carrier mother
$X^HX^h$
$X^H$
$X^h$
$X^HX^H$
Normal daughter
$X^HY$
Normal son
$X^HX^h$
Normal carrier daughter
$X^hY$
Hemophiliac son
Genotypic ratio = ¼ $X^HX^H$ : ¼ $X^HX^h$ : ¼ $X^HY$ : ¼ $X^hY$
Phenotypic ratio = ½ normal females : ¼ normal males : ¼ hemophiliac males

**FIGURE 8-20.** A cross of parents with normal blood clotting shows the probability of hemophiliac offspring if the mother carries the hemophilia gene. A female hemophiliac is rare because she must receive a hemophilia gene from each parent. Why is the probability of this occurrence low?

## 8:10 Sex-linked Diseases

Sex-linked diseases are those diseases with genes that are carried on the sex chromosomes. Therefore, they will appear more often in one sex. These diseases, just as those discussed earlier, are caused by abnormal alleles.

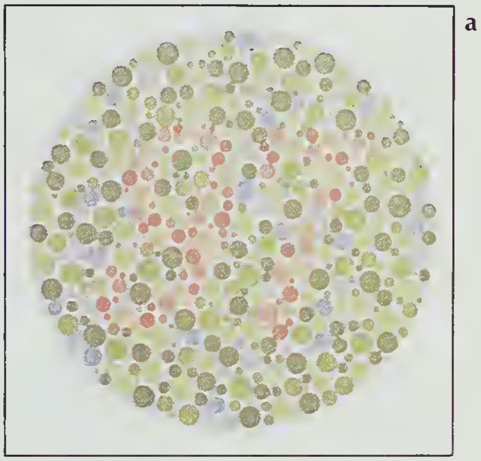
- **Hemophilia** (hee muh FIHL ee uh). In persons with hemophilia, the blood will not clot properly. The disease is the result of a sex-linked recessive gene. The alleles for hemophilia and normal blood clotting are carried on the X chromosome. The Y chromosome carries no matching alleles. Thus, a male is more likely to get the disease than a female. His cells only need one gene for the disease trait to appear. The chances of getting one recessive allele are greater than the chances of getting two recessive alleles. If a male gets the one recessive allele, his blood will not clot properly. The recessive gene results in the failure to make a substance which must be in the blood for clotting to occur.

There is no cure for hemophilia. People with the disease lose large amounts of blood from events that are minor to most people. Usual treatment consists of blood transfusions. Clotting factors, chemicals that help clot blood, are also given to hemophiliacs.

- **Colorblindness.** Some humans do not see red or green. Instead, anything that is red or green appears as gray. These people have red-green color blindness, a sex-linked trait. The genes for color vision are located on the X chromosome. As in other sex-linked traits, a male is more likely to have the defect. Females are often carriers.

**FIGURE 8-21.** (a) Charts are used to detect red-green color blindness. Persons with normal vision can see a number in the top chart. What is the number? (b) To someone who is red-green color-blind, the chart appears as tones of gray.

a



*Russ Kinne for Photo Researchers*

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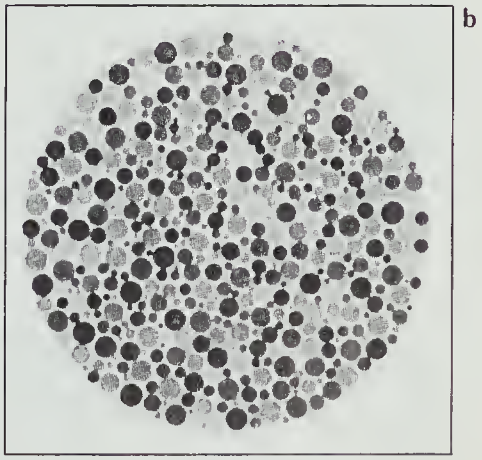
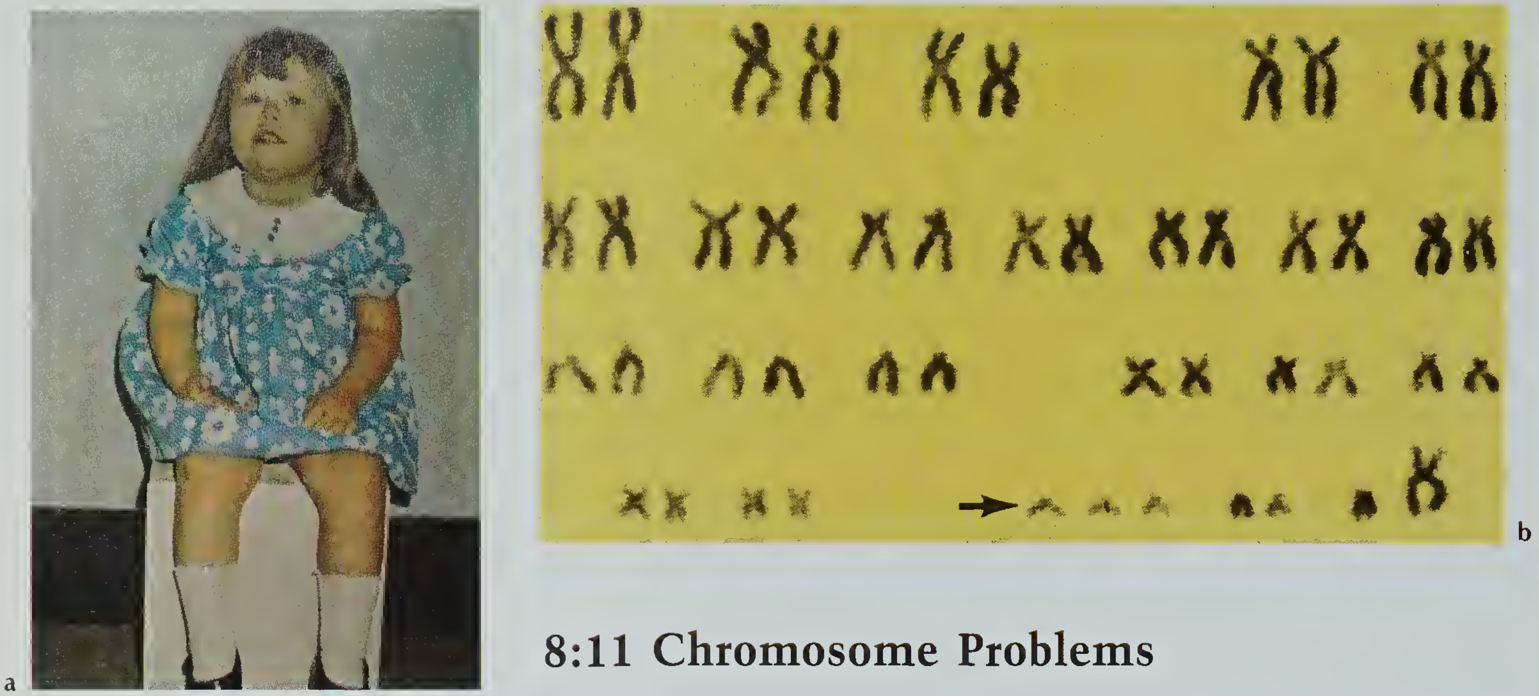


*Russ Kinne for Photo Researchers*



Department of Pediatrics, Children's Hospital, Columbus, OH

Medical Genetics Laboratory, Children's Hospital, Columbus, OH

**FIGURE 8-22.** (a) A child with Down syndrome has (b) a karyotype that shows three chromosomes (arrow) for one of the pairs.

## 8:11 Chromosome Problems

Down syndrome may be caused by nondisjunction.

- **Down Syndrome.** Nondisjunction (Section 8:4) can cause a variety of human defects. One cause of a disease called Down Syndrome is the nondisjunction of autosomes. A person with Down Syndrome caused in this way has one extra chromosome in the cells. Recall that when chromosomes are identified, they are numbered. A Down Syndrome cell has three number 21 chromosomes.

Symptoms of this disease include mental retardation, abnormal facial traits, short arms and legs, and internal defects. At present, there is no treatment for the disorder.

Defects can occur from chromosome abnormalities other than an incorrect chromosome number. Sometimes, parts of an entire chromosome can become attached to other chromosomes. Another cause of Down Syndrome results from this process. Also, a fragment of a chromosome may be missing in some cases.

In Turner syndrome, a female has one X chromosome and no other sex chromosomes.

- **Turner Syndrome** results from nondisjunction of the sex chromosomes. The person has one X chromosome and no Y chromosome. Because there is no Y chromosome, the person is female. However, she fails to develop normal characteristics and is sterile. A person with Turner Syndrome is usually short and sometimes has below average intelligence.

A person with Klinefelter syndrome is a male with two X chromosomes and one Y chromosome.

- **Klinefelter Syndrome** results in an XXY chromosome pattern. Those with this disease are males. They fail to develop normal sex characteristics and are usually sterile. They also have very long arms and legs and below average intelligence.

### REVIEWING YOUR IDEAS

13. List several human genetic diseases and their causes.
14. How can nondisjunction cause genetic disease?

## ADVANCES IN BIOLOGY

## 8:12 Detecting Human Genetic Disease

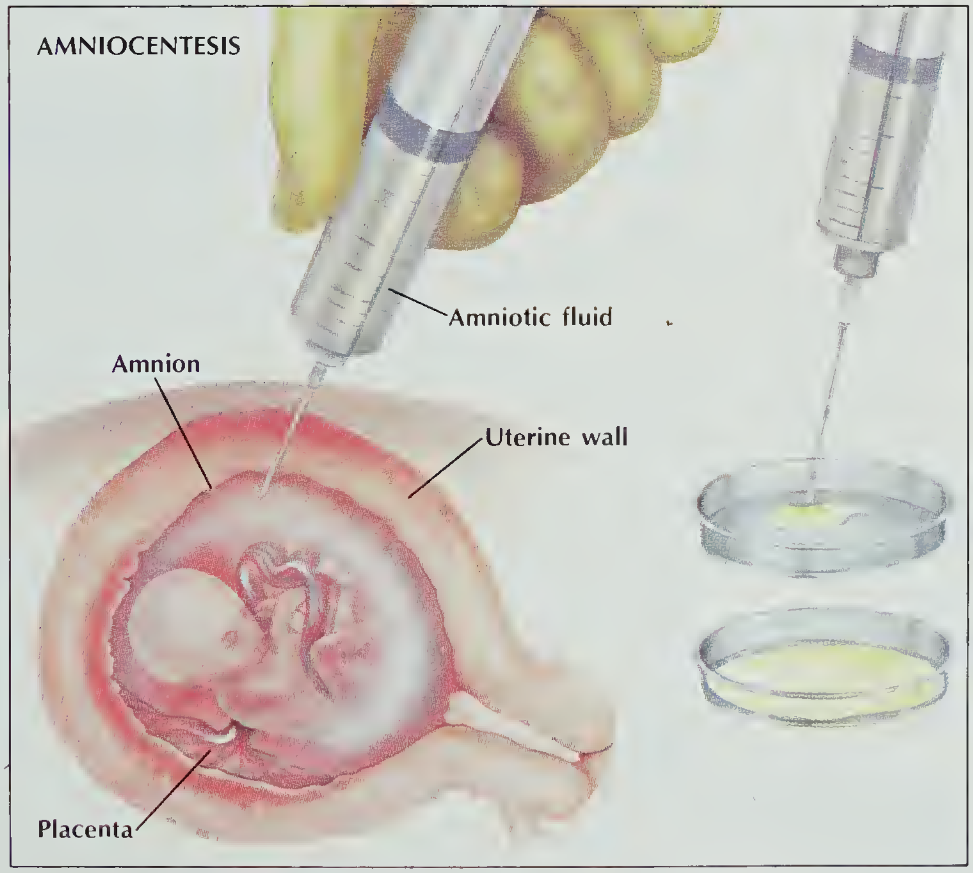
More than 200 000 babies each year in the United States are born with genetic disorders or birth defects. Although many of them are minor, others cause severe health problems. Some cause death. Several techniques allow physicians to detect dangerous problems in the fetus (unborn child).

**Amniocentesis** (am nee oh sen TEE sus) is a process in which a sample of fluid surrounding the fetus is withdrawn through a long, thin needle. The fluid can be analyzed for the presence or absence of certain chemicals which indicate genetic disease. Examples of diseases detected are hemophilia, some forms of muscular dystrophy, Tay-Sachs disease, and sickle-cell anemia.

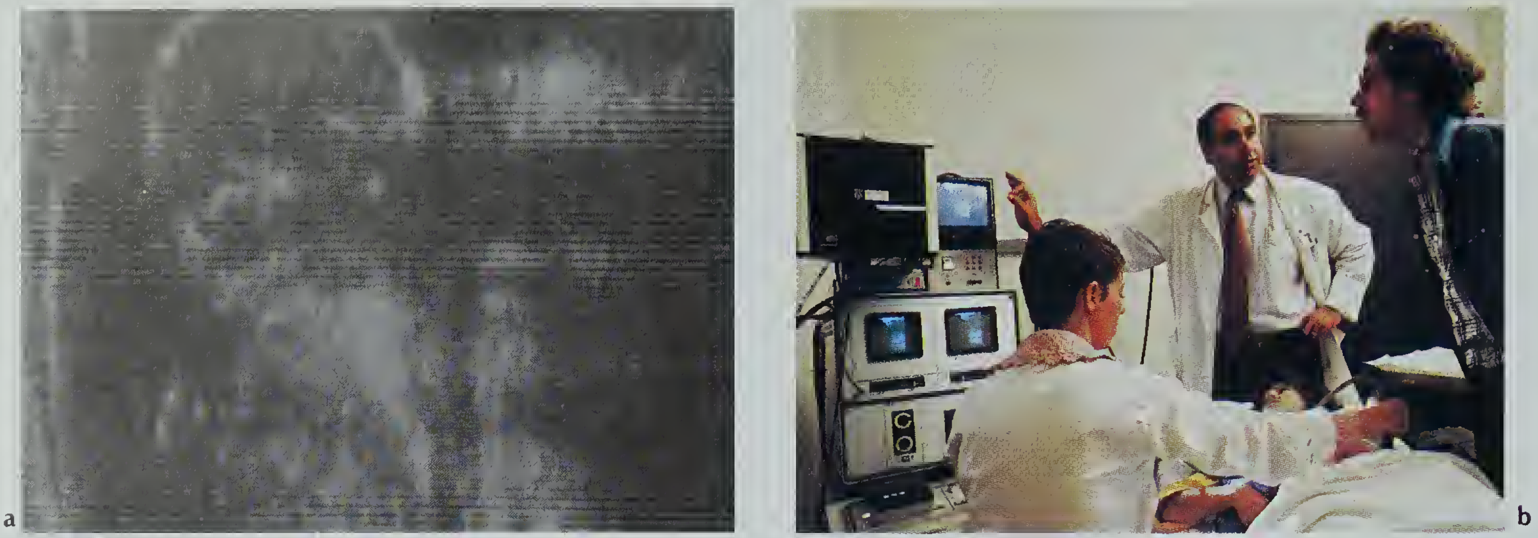
Some diseases are detected by studying fetal cells found in the fluid that is withdrawn in amniocentesis. The chromosomes in these fetal cells can be studied. Recall that the chromosomes, when photographed and paired, are called a karyotype. Karyotypes of cells can reveal if the fetus has certain diseases, such as Down Syndrome. Other examples of diseases that show in karyotypes are Turner and Kleinfelter Syndromes. (Sex of the fetus may also be determined this way.)

Amniocentesis can be used to determine if a fetus has certain genetic diseases.

**FIGURE 8-23. In amniocentesis, fluid from the amnion is withdrawn. The fluid contains some of the unborn baby's cells. The cells are grown and their chromosomes are analyzed. Certain diseases can be determined from this procedure.**



Kenneth Garrett



Gerard Photography

Kenneth Garrett

FIGURE 8-24. (a) This echogram shows the head and shoulders of an unborn baby. (b) Sound waves emitted from the probe at the mother's abdomen "echo" back from the fetus resulting in the production of the image on the screen.

Certain physical abnormalities can be detected using ultrasonography.

A technique called **ultrasonography** (ul truh suh NAHG ruh fee) can be used to determine the position and anatomy of a fetus. An ultrasound probe is passed over the mother's abdomen. It emits high frequency sound waves which "echo" from the tissues of the fetus. Different tissues send back different waves which, together, form an image on a screen. By studying these images, called echograms, physicians can spot abnormalities such as certain forms of heart disease. Ultrasound is also used prior to amniocentesis. Its use ensures that the needle is inserted such that the fetus is not harmed.

Direct observation of a fetus may be made using an endoscope.

**Fetoscopy** (fee TAHS kuh pee) allows direct observation of the fetus and surrounding tissues. After using ultrasound to determine the position of the fetus, a device called an **endoscope** is used. The endoscope is inserted through a small incision in the mother's abdomen. The fetus is viewed directly through the endoscope tube. An image of the fetus is seen on a screen, too. Using other tools inserted into the endoscope, small samples of skin or blood may be withdrawn for study. These may reveal abnormalities.

For the most part, these techniques are used to determine whether disease exists, not to cure the disease. In some cases, physicians can be prepared for treatment or surgery as soon as the infant is born.

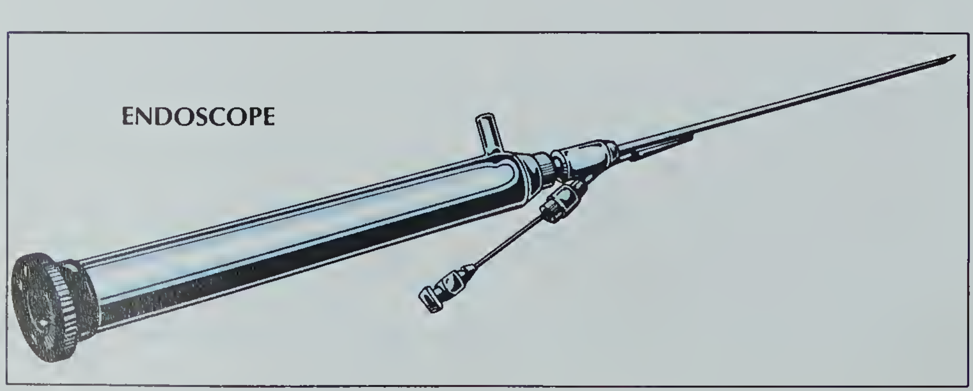


FIGURE 8-25. An endoscope is an instrument used for seeing inside the body. They are used to examine internal organs and fetuses. Some surgery can be done through an endoscope.

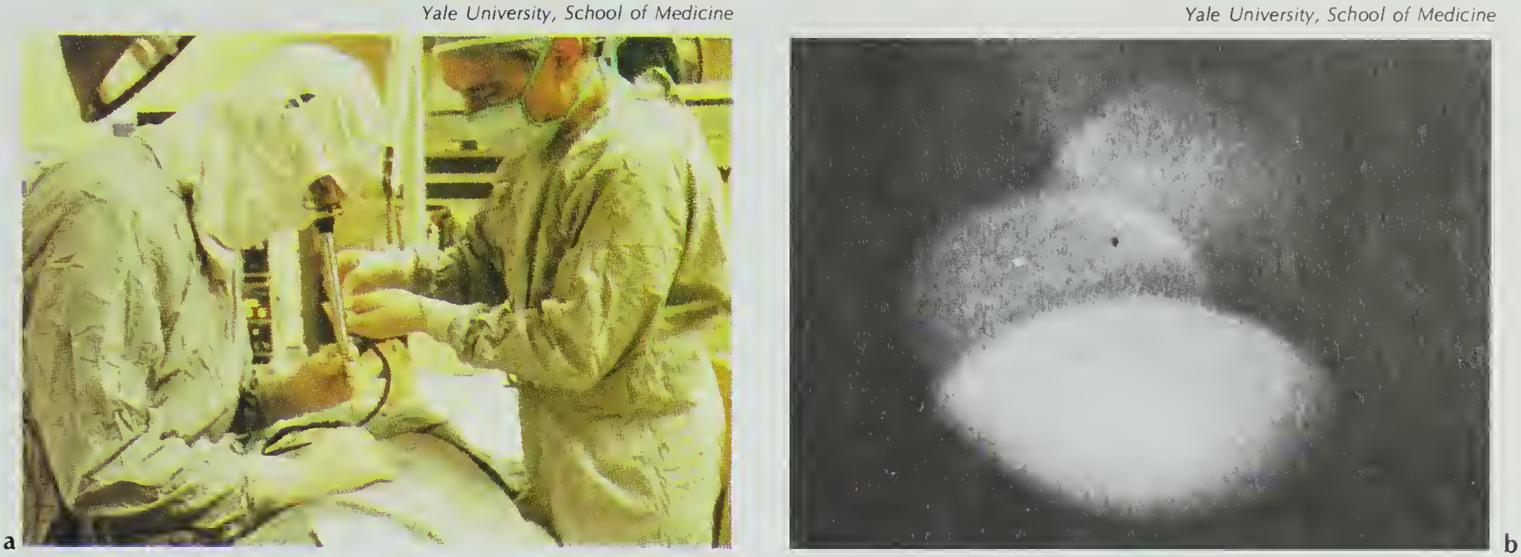

Yale University, School of Medicine
a
Yale University, School of Medicine
b

**FIGURE 8-26. (a) Fetoscopy is a procedure of inserting an endoscope into the abdomen to examine or medically treat the fetus. (b) This picture shows the bottom of the toes of a fetus as seen through an endoscope.**

Certain problems, though, can be treated before birth. Fetoscopy has been used to give a transfusion to a fetus. It has also been used to remove excess fluid from around a fetus' brain. Recently, an operation was done that temporarily solved a problem in the urinary system of a fetus. The outlook for fetal medicine is bright. It is hoped that a greater number of diseases will be detected, and that more fetuses will benefit from early medical treatment.

In some cases fetoscopy can be used to treat a fetus.

## CHAPTER REVIEW

### SUMMARY

1. The movements of chromosomes during meiosis fit with Mendel's Laws about the activities of genes. Alleles are carried on homologous chromosomes.
2. Thomas Hunt Morgan discovered that certain traits are sex-linked. Alleles for these traits are carried on the X chromosomes but not on the Y chromosomes.
3. Bridges' discovery of nondisjunction in *Drosophila* confirmed that genes are located on chromosomes—the chromosome theory of heredity.
4. Bridges' work also revealed the basis for sex determination in *Drosophila*. Later work showed that the basis for sex determination in humans is slightly different.
5. Genes located on the same chromosome are said to be linked. Because linked genes do not assort independently during meiosis, gene linkage reduces the chances for genetic recombination and variety among offspring.
6. Crossing-over is an exchange of the same segments of chromosomal material between two strands of a tetrad. Crossing-over tends to increase variety among offspring by recombining linked genes.
7. The frequency of crossing-over between linked genes can be used in making genetic maps. The more crossing-over that occurs between two genes, the farther apart the genes are.
8. Certain traits show continuous variation. Multiple genes probably control the expression of these traits.
9. Environment may affect the expression of genes.

## CHAPTER REVIEW

10. Genetic abnormalities may result in a variety of human diseases. These diseases may be caused by the presence of alleles for the disease or by an abnormal number of chromosomes.
11. Certain genetic diseases are sex-linked because the genes for the traits are present on the X chromosome.
12. Amniocentesis, ultrasonography, and fetoscopy are methods used to detect human genetic disease of a child before its birth. Treatment is sometimes given before birth.

## LANGUAGE OF BIOLOGY

amniocentesis
autosomes
chromosome theory of heredity
continuous variation
crossing-over
fetoscopy
gene linkage
genetic map
hemophilia
lethal gene
multiple genes
nondisjunction
sex chromosomes
sex-linked characteristic
ultrasonography

## CHECKING YOUR IDEAS

*On a separate paper, complete each of the following statements with the missing term(s). Do not write in this book.*

1. Expression of some genes depends upon the organism's ______ .
2. ______ are located on chromosomes.
3. ______ is the failure of chromosomes to separate properly during meiosis.
4. A couple has three sons. The chance that their next child will be a boy is ______ .
5. People with sickle-cell anemia have red cells which do not carry enough ______ .
6. If a color-blind man marries a woman heterozygous for normal color vision, ______ of their offspring are expected to be color-blind.
7. Genes located on the same chromosome are said to be ______ .
8. In order for a white-eyed female fruit fly to be produced, both parents must carry a (n) ______ gene.
9. A human with an XXXY chromosome pattern would be a(n) ______ .
10. Linked genes may be separated by ______ .

## EVALUATING YOUR IDEAS

1. Did observation of meiosis verify that genes are carried on chromosomes? Explain.
2. How many pairs of autosomes does a human cell contain?
3. A couple has five daughters. What are the chances that their next offspring will be female?
4. How did Morgan test his hypothesis about sex-linked characteristics?
5. Did the results of Morgan's test (Question 4) verify that genes are carried on chromosomes? Explain.
6. How is nondisjunction explained?
7. State the chromosome theory of heredity.
8. In a certain organism, one chromatid contains the genes *A* and *b*. Its homologous chromatid contains *a* and *B*. What combinations of genes would be found in gametes of this organism if no crossing-over occurs? What combinations of genes might be found in the gametes if crossing-over does occur?
9. Several plants of the same kind vary in height from 15 to 30 cm. How can this be explained?
10. Explain how the cells of a human might contain two X chromosomes and one Y chromosome. What sex is the person?
11. Why are identical twins useful for studying effects of environment on development?
12. In *Drosophila*, the gene for red eyes, *R*, is dominant to the gene for white eyes, *r*. This trait is sex-linked. Determine the probable

genotypic and phenotypic ratios expected from a cross between (a) a heterozygous female and a red-eyed male, (b) a heterozygous female and a white-eyed male, (c) a homozygous dominant female and a red-eyed male, and (d) a homozygous dominant female and a white-eyed male.

**13.** In humans, the gene for normal blood clotting, *H*, is dominant to the gene for hemophilia, *h*. The trait is sex-linked. A woman with normal blood clotting has four children. They are a normal son, a hemophiliac son, and two normal daughters. The father has normal blood clotting. What is the probable genotype of each member of the family?

**14.** In humans, the gene for normal color vision, *C*, is dominant to the gene for red-green color blindness, *c*. The trait is sex-linked. The gene for brown eyes, *B*, is dominant to the gene for blue eyes, *b*. Calculate the probable genotypic and phenotypic ratios of the children born to a blue-eyed woman who is heterozygous for color vision and a heterozygous brown-eyed man who is color blind.

**15.** Explain why blue eyes and blond hair or brown eyes and brown hair are commonly inherited together.

**16.** List several factors which cause human genetic disease. Give several examples of diseases caused by each factor.

**17.** Discuss several techniques which are used to detect genetic diseases in human fetuses.

## APPLYING YOUR IDEAS

**1.** Alleles *A*, *B*, and *C* are known to be linked. *A* crosses over with *B* ten percent of the time. *A* crosses over with *C* twenty percent of the time. Genes *B* and *C* cross over ten percent of the time. What is the sequence of the genes on the chromosome?

**2.** In a certain plant, tall, *T*, is dominant to short, *t*. Red flowers, *R*, are dominant to white flowers, *r*. A gardener crosses a *TtRr* plant with a *ttrr* plant. Seeds from this cross produce 52 plants which are tall and red and 48 plants which are short and white. Explain these results.

**3.** What would be the result if chromosome parts crossed over between the two chromatids of a chromosome?

## EXTENDING YOUR IDEAS

**1.** Determine the heights of a large number of your classmates. Draw a graph comparing the number of people versus heights. What genetic pattern does the graph suggest?

**2.** Conduct an experiment with *Drosophila* to show the inheritance of linked genes and the concept of crossing-over.

**3.** Obtain some tobacco plant seeds. Allow the seeds to germinate under normal lighting conditions. Calculate the phenotypic ratio of leaf color among the seedlings. Repeat the procedure but this time vary lighting conditions to include darkness, normal light, and bright light. Compare your data with those from your first experiment.

## SUGGESTED READINGS

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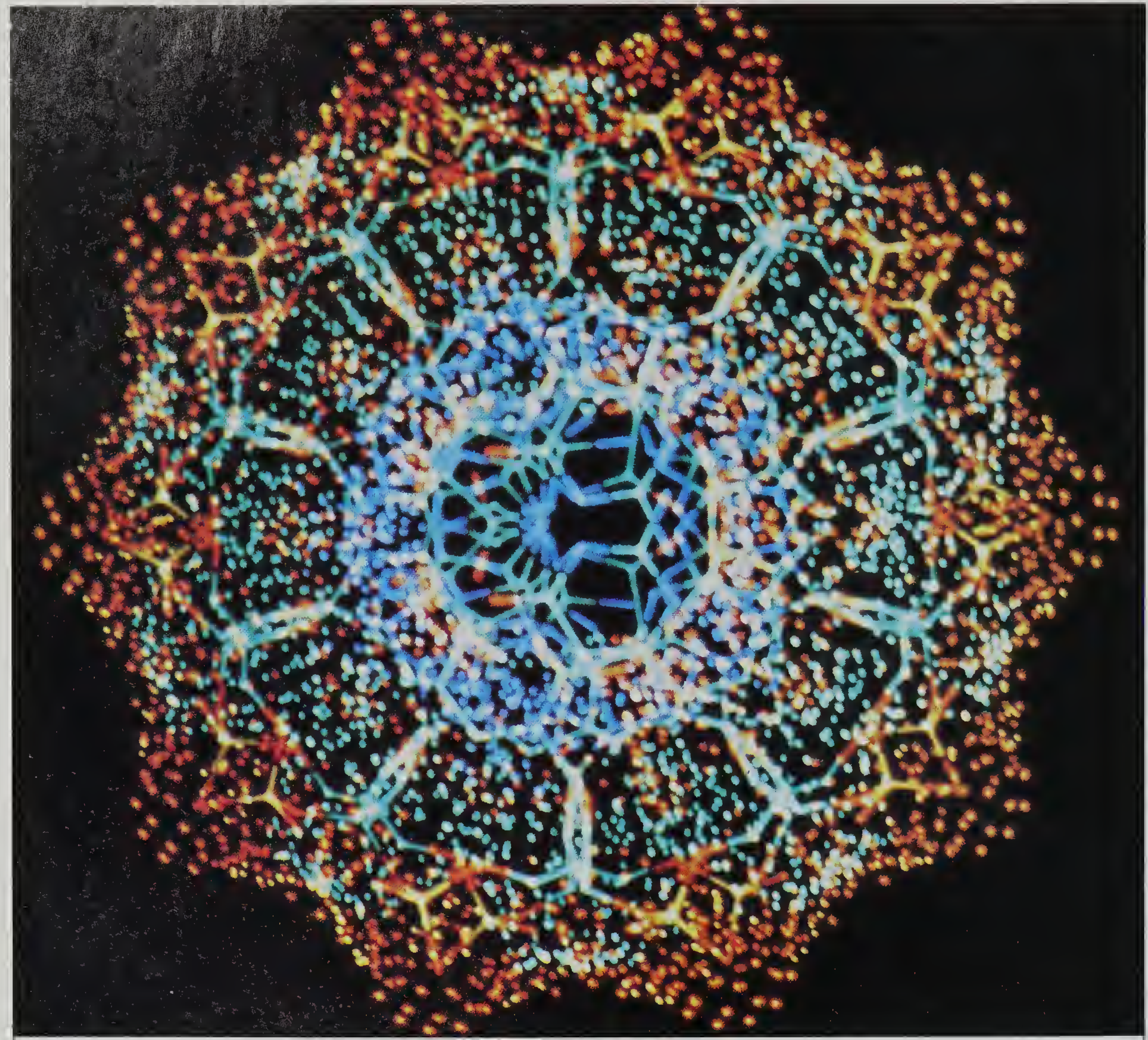


UCSF/Rainbow

*Generation after generation, genes are replicated and passed on to offspring, and the gene products result in certain traits. How is genetic information passed on in such exact form? A chemical called DNA is responsible. Shown here is a computer drawing of DNA, viewed as you would see it if you were looking down the center of the molecule. DNA directs replication of cells and functions as the chemical of heredity. How does DNA control heredity?*

Chapter
9

# THE GENETIC CODE

The gene is the unit of heredity. Combinations of genes produce certain, predictable features among offspring. What is a gene? Of what materials are genes composed? How does a gene duplicate? How does it regulate the activities of cells?

**GOAL:** You will gain an understanding of the chemical basis for the transmission of traits, and of the features of genes and their chemical structure.

## STRUCTURE OF DNA

### 9:1 Bacterial Transformation

Experiments with the bacterium *Pneumococcus* (new muh KAHK us) helped answer some of these new and challenging questions. Several strains or varieties of this bacterium are known. (Strains differ genetically.) One strain consists of cells which are enclosed within a capsule. This strain is referred to as "smooth." Another strain has cells not enclosed by a capsule. It is referred to as "rough." Smooth cells cause the disease pneumonia, but rough cells do not.

Smooth and rough are forms of *Pneumococcus* controlled by different genes.

In 1928, Fred Griffith injected a mixture of heat-killed, smooth cells and living, rough cells into healthy mice. Griffith expected the mice to remain healthy because rough cells do not cause pneumonia and because the smooth cells were dead.

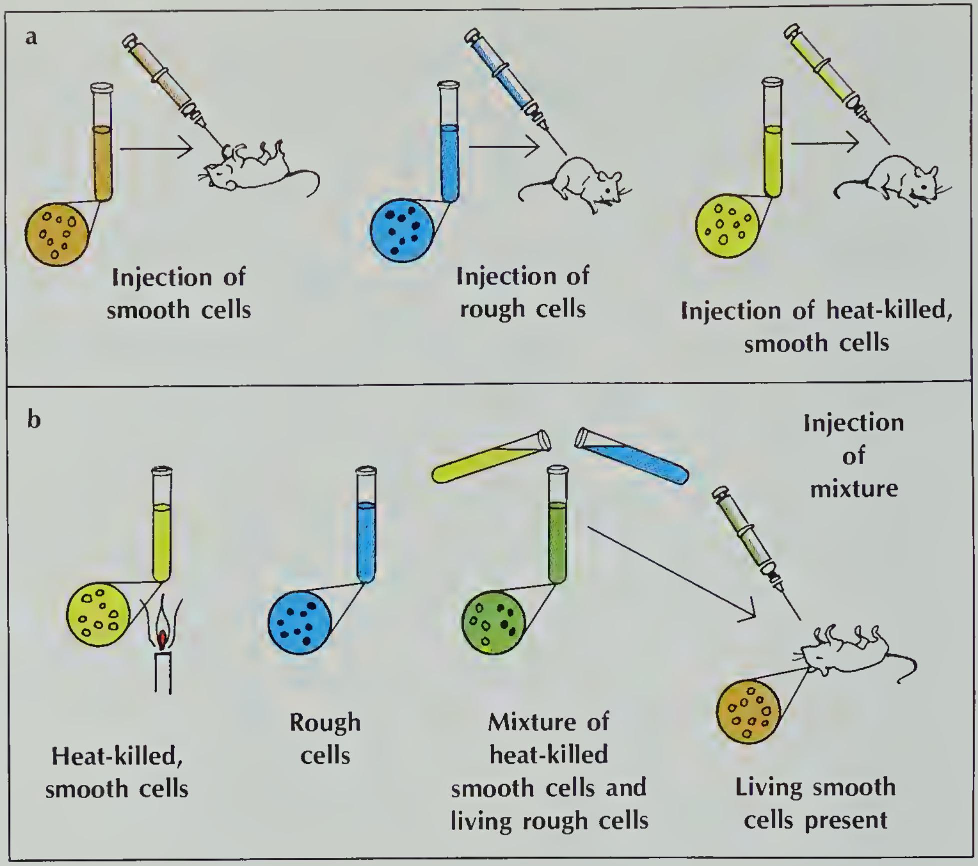

a
Injection of smooth cells
Injection of rough cells
Injection of heat-killed, smooth cells
b
Heat-killed, smooth cells
Rough cells
Mixture of heat-killed smooth cells and living rough cells
Injection of mixture
Living smooth cells present

**FIGURE 9-1.** (a) Injected smooth cells kill mice; rough cells or dead smooth cells do not. (b) When dead smooth cells and rough cells are mixed, bacterial transformation occurs. The injected mixture kills mice.

However, some of the mice died of pneumonia. On examining the blood of the dead mice, Griffith made an unexpected observation—living, smooth *Pneumococcus* cells were present (Figure 9-1)! Had the dead cells returned to life? Of course not.

One strain of cells altered the heredity of the other strain.

There was one reasonable explanation—the dead, smooth cells must have directed the rough cells to become smooth. A hereditary trait of the rough cells must have been changed. This kind of change of trait in bacteria is called a **bacterial transformation.**

It was assumed that a chemical was responsible for the bacterial transformation.

How could such a change in traits occur? Scientists suspected that something, most likely a chemical, in the dead, smooth cells caused the change. If a chemical did cause the change, then that chemical alone could cause a change in heredity.

To test this hypothesis, colonies of smooth cells were grown on a nutrient medium in culture dishes. When enough colonies had formed, they were ground up to release the chemicals from the cells. The chemicals were removed, or extracted, from the cells. The solution of the removed chemicals was called an **extract.** The scientists thought that a chemical in the extract would cause transformation.

The extract from the smooth bacteria was added to the culture medium in each plate of another set of culture dishes. These plates were then inoculated with rough cells only. When many colonies had formed, cells were isolated for study. On observation many of the cells were smooth! Also, the new smooth cells produced more smooth cells. When injected into healthy mice, the new smooth cells caused pneumonia (Figure 9-2). Controls to which no extract was added showed no bacterial change. They did not cause pneumonia when injected into mice.

The extract had changed the heredity of the rough cells just as the hypothesis had predicted. A chemical in the extract was involved in heredity. It had changed the form of the one strain and had affected the cells' offspring. This chemical was called the **transforming principle.**

The transforming principle was not easy to identify. But in 1944, it was identified as **deoxyribonucleic acid (DNA)** (Section 3:16). DNA was discovered in 1871, but it was not thought to be involved in heredity until this work was done.

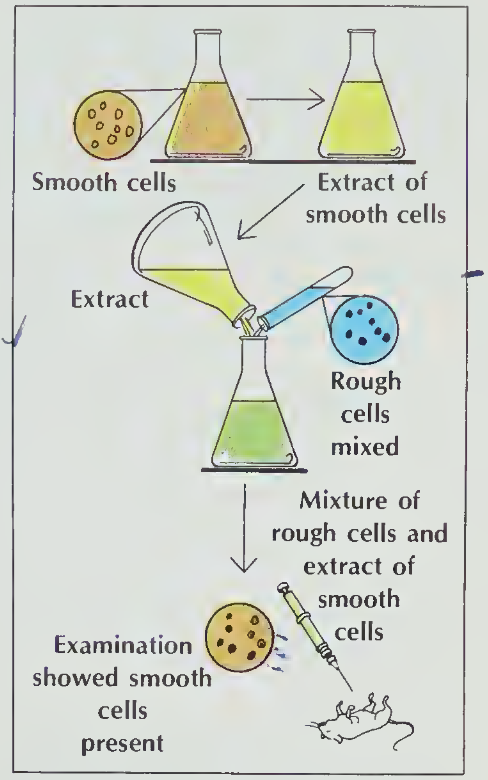

Smooth cells
Extract of smooth cells
Extract
Rough cells mixed
Mixture of rough cells and extract of smooth cells
Examination showed smooth cells present

FIGURE 9-2. A chemical in the extract prepared from smooth bacteria caused some rough cells to become smooth.

## 9:2 A Model

Other research supported DNA as the chemical of heredity. Biochemists found that DNA is a complex molecule composed of three smaller parts. The parts are a sugar (deoxyribose), phosphate groups, and compounds called bases. The three parts combine to form subunits called **nucleotides** (NEW klee uh tidez). Many nucleotides joined together form a DNA molecule.

DNA contains the bases adenine, guanine, cytosine, and thymine.

In DNA, there are four different bases. They are **adenine** (AD un een), **guanine** (GWAHN een), **thymine** (THI meen), and **cytosine** (SITE uh seen). In Figure 9-3, the chemical structure of each base is shown. Note that each base contains nitrogen. Sometimes the bases in nucleic acids are called nitrogen bases. The chemical structure of each base is shown in the figure on top of a colored shape. Each shape refers to that specific base in the figures that follow. You will easily be able to tell what chemicals are being shown in the drawings if you keep in mind what the shapes represent as you examine the other figures in this chapter.

FIGURE 9-3. The four bases of DNA all contain nitrogen. They are shown on colored shapes that will be used throughout the chapter to represent these chemicals.

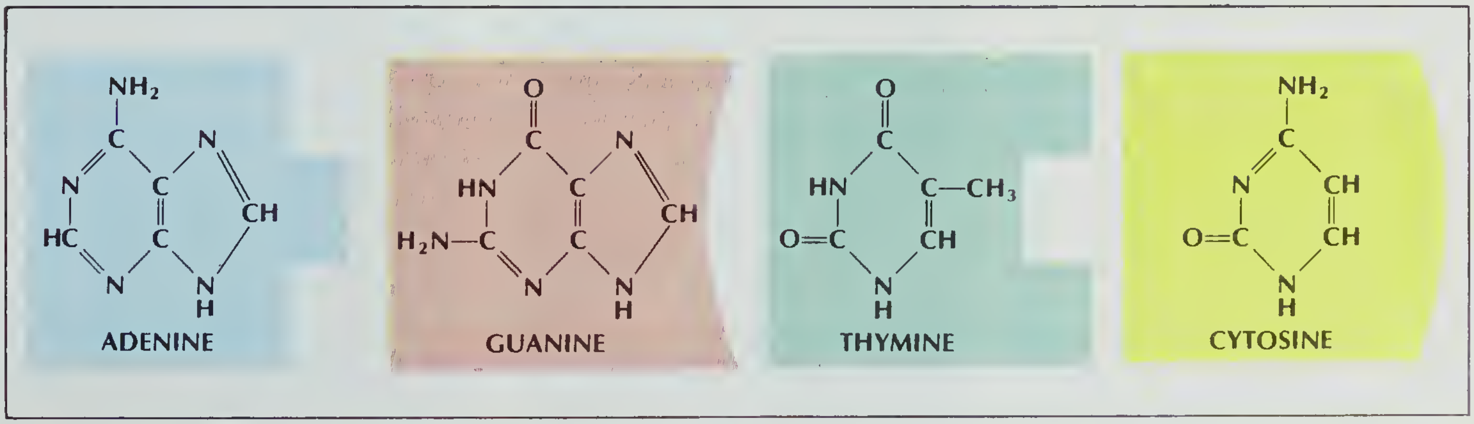
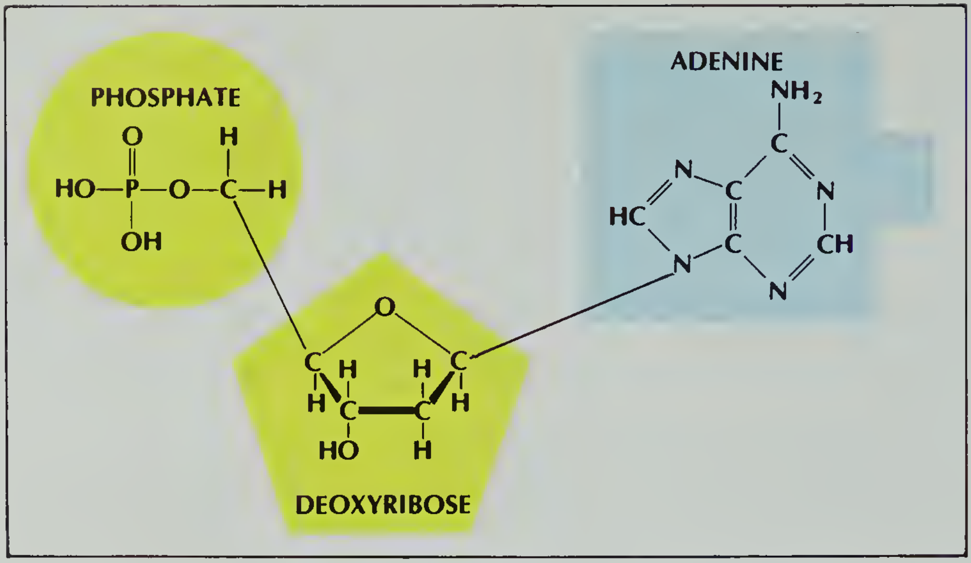


**FIGURE 9-4.** The structural formula of an adenine nucleotide shows a molecule of deoxyribose, a phosphate group, and adenine. They are shown on colored shapes that will be used throughout the chapter to represent these chemicals.



A nucleotide is named for the base which it contains.

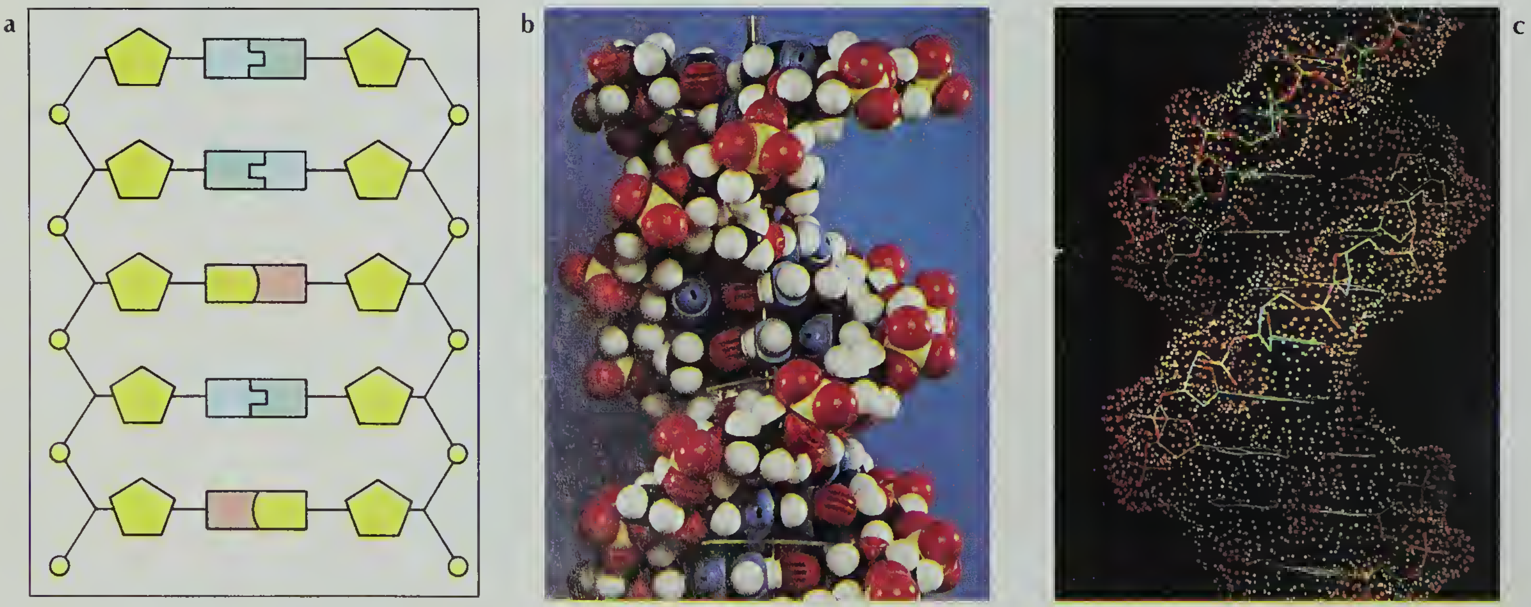
Each nucleotide is named for the base it contains. Adenine nucleotide contains adenine. Figure 9-4 shows the arrangement of the three parts of a nucleotide. Note again the color shapes that will be used in the figures to follow.

A model of DNA, to be of value, must explain how copies of DNA are made.

James Watson and Francis Crick combined the results of their own research with the results of other scientists. Much of the experimental work was done by Maurice Wilkins. Watson and Crick presented a model of DNA in 1953. A model is a description that helps you picture something. A model can be used to explain known facts. If the model does not explain the facts, it is of little use. The structural model of DNA had to explain how new cells get exact copies of DNA.

The Watson and Crick DNA model is built like a ladder (Figure 9-5) made of two chains of nucleotides joined together. The uprights of the ladder are composed of the sugar and phosphate parts of the nucleotides. The rungs are made up of the

**FIGURE 9-5.** (a) In the ladder model of DNA structure, the uprights are the sugar and phosphate molecules. The rungs are the matched base pairs. (b) In a 3-D model with colored balls for atoms, the twist of the DNA ladder can be seen. (c) A computer drawing of DNA also shows the twist in the ladder.



Ira Wyman/Sygma

McCoy/Langridge, UCSF-Rainbow

nitrogen bases of the nucleotides. Bases have shapes that fit together only in certain ways, much like an enzyme and a substrate fit (Section 4:5). *Adenine nucleotides always join with thymine nucleotides and guanine nucleotides always join with cytosine nucleotides.* Adenine fits thymine and guanine fits cytosine. Notice that the chains of nucleotides are twisted around each other to form a double spiral or double helix (HEE lihks). Watson and Crick included as part of their model this twisting of DNA because the helix is the most stable form possible.

In DNA, adenine nucleotides join with thymine nucleotides, and guanine nucleotides join with cytosine nucleotides.

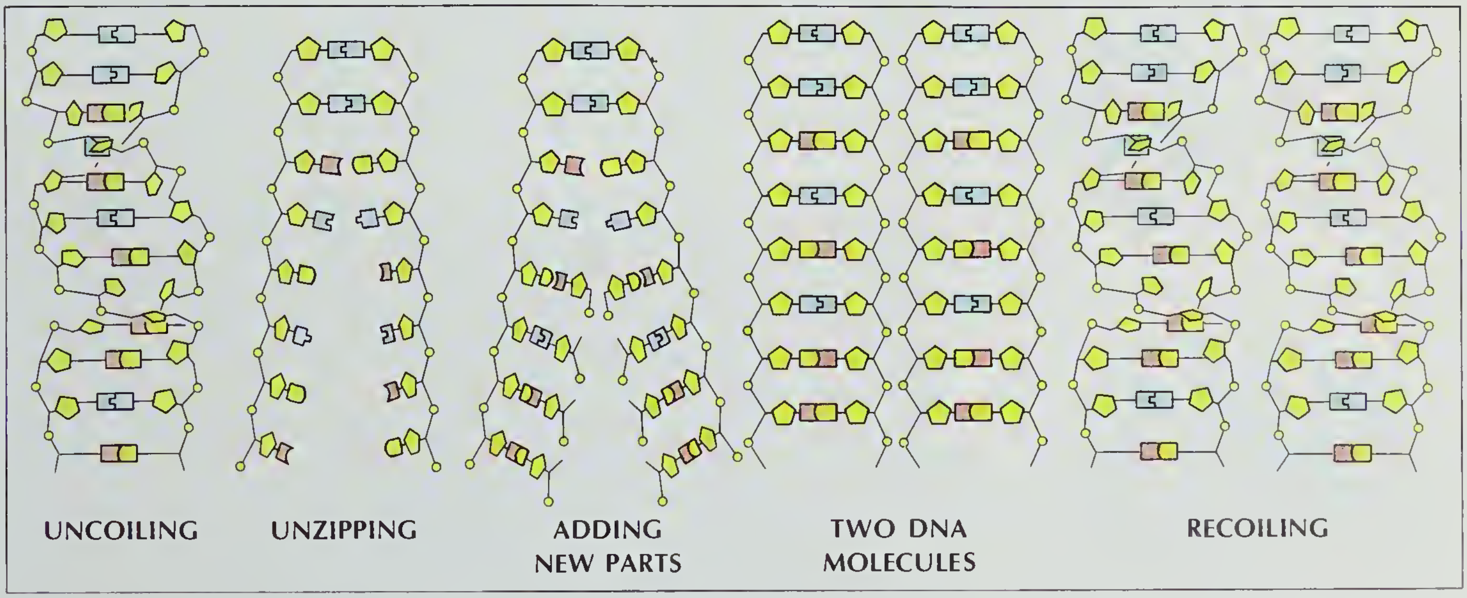
DNA is in the form of a double helix.

## 9:3 Replication of DNA

The Watson and Crick model of DNA structure explains the models of the mechanism of DNA **replication** (duplication). Of particular importance to replication is the pairing of bases. By this model of replication, the DNA molecule first unwinds from its twisted form. It then "unzips." That is, weak bonds that hold the bases of the nucleotides together break and the two strands separate. As the separation occurs, the bases of the nucleotides become exposed to the contents of the nucleus. In the nucleus there are many nucleotides which already have been formed. *These nucleotides join the exposed bases only in certain ways (adenine with thymine, guanine with cytosine).* The nucleotides added to one strand of the original DNA molecule form a sequence exactly like that of the other strand. Eventually, joining of new nucleotides to the exposed bases is completed. The nucleotides are joined to each other. The result is two DNA molecules exactly like the original molecule (Figure 9-6). This entire process proceeds by the action of several enzymes and the energy of ATP.

As the DNA molecule "unzips," nucleotides present in the nucleus join with the exposed nucleotides; A with T, and G with C.

**FIGURE 9-6. Exact duplication of a DNA molecule involves specific base pairing. The two resulting molecules are identical.**



Replication of chromosomes during mitosis and meiosis is essentially a replication of DNA.

The structure and replication of DNA fit together with the processes of mitosis and meiosis in eukaryotic cells. DNA is the material which makes up genes and thus, chromosomes. Chromosomes replicate prior to mitosis and meiosis. As a result, new cells and new organisms have the proper genetic instructions. This replication of chromosomes is essentially a replication of DNA molecules. The number of DNA molecules per chromosome is uncertain. Regardless of the number, each DNA molecule must be replicated.

There are models other than the one presented to explain DNA replication. All of them involve proper base pairing. It is certain that much is yet to be learned about this process.

### REVIEWING YOUR IDEAS

1. Define the transforming principle. Why is it so named?
2. What compound is the transforming principle?
3. What is a nucleotide? Of what is it composed? How is a nucleotide named?
4. Explain the pairing of nucleotides in the DNA molecule.
5. Compare the DNA molecule to a ladder.
6. Briefly describe a model for DNA replication.

# THE ROLE OF DNA

## 9:4 Proteins in Cells

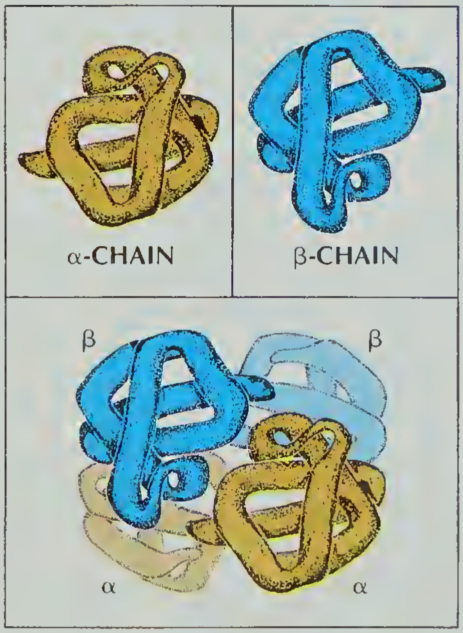
Mendel first suggested hereditary units (genes) in 1866. Almost a century later genes were found to be made of DNA. The next logical question was how do the genes, regions of DNA molecules, work? What does DNA do?

You recall that proteins are unique organic molecules (Section 3:15) composed of different combinations of about twenty amino acids. A protein may consist of hundreds, even thousands, of amino acids. A certain amino acid may appear many times in a protein. The order of amino acids varies greatly from protein to protein.

Besides the order of amino acids, other factors also make one protein different from all others. The long chains of amino acids are coiled and folded. Thus, the protein has a specific, three-dimensional shape.

As an example, the structure of the protein hemoglobin is that of four chains together. A representation of the 3-D shape of hemoglobin was shown in Figure 8-16. In Figure 9-7, the chains of the molecule are shown folded and coiled as they would be in the final molecule. Remember that each chain is made of a specific sequence of amino acids.

**FIGURE 9-7.** Hemoglobin is a blood protein made of two α chains and two β chains of amino acids. The chains are coiled and folded in a specific 3-D shape.



Proteins have specific jobs in cells. Each cell contains thousands of different protein molecules. Many of these are enzymes. The three-dimensional nature of proteins gives each enzyme a specific shape. Its shape "fits" only certain substrates (Section 4:5).

Think of a cell as a constantly working factory into which raw materials are always being brought. These materials will be used in certain ways according to the enzymes present. Each cell is what it is because of its enzymes. Cells differ because each cell's enzymes are different and so their chemical reactions are different. The raw materials are about the same for most cells, but the ways the materials are used are different. Thus, each type of cell is different.

Enzymes control a cell's metabolism. Uniqueness of cells is due to the combination of enzymes at work in them.

Many proteins are not enzymes. They function in many other ways in cells. They can be parts of cellular structures such as the plasma membrane, chromosomes, and organelles. Some are carrier molecules (Section 5:6) and some have other functions (Sections 19:11 and Chapter 29).

Not all proteins are enzymes. Some have other roles.

## 9:5 Genes and Proteins

Might there be a relationship between genes and proteins? Proteins are unique and genes are unique. Perhaps the role of DNA (the genes) is to guide the synthesis of proteins. This idea could explain, for example, the difference between healthy people and those with sickle-cell anemia. Perhaps the difference in their hemoglobins is caused by a difference in their genes.

Athough the explanations were logical, there was no experimental evidence for them. In 1941, such evidence was provided. It was shown that genes work by forming enzymes.

*Today, it is known that genes control the synthesis of every type of protein, not just enzymes.* Also, a gene may be responsible for the synthesis of only a single polypeptide (a part of a protein). Hemoglobin is made up of two different pairs of polypeptides that are formed by two different genes. After they are made, they join with one another to form the hemoglobin molecule.

Genes control the synthesis of proteins and polypeptides.

J. Gnau, A. Ottolenghi, G. Marzluf/OSU

**FIGURE 9-8. Initial experiments showing that genes function by producing proteins were done with this mold, *Neurospora crassa*. The mold is shown here growing inside a flask.**

## 9:6 DNA Code

DNA contains information for protein synthesis. The information is in a code. The sequence of base pairs from the top to the bottom of the "ladder" makes one DNA molecule different from another. It seems reasonable that this sequence of bases is the code.

Recall proteins are composed of amino acids. The order and arrangement of amino acids make each protein different. There are twenty amino acids but only four kinds of bases in DNA. A single base cannot represent an amino acid. Also a combination of two bases in a row along the DNA ladder cannot represent an amino acid. There are only sixteen possible combinations of the four bases two at a time. Three bases in a row, however, give more than the twenty combinations needed. In fact, it provides sixty-four possible code "words." Experiments have shown that three bases in a row do act as the code for amino acids. The three bases representing an amino acid are known as a **codon** (KOH dahn). Some amino acids have more than one codon. In other words, you can get the same amino acid in more than one way (Table 9-1).

**TABLE 9-1. AMINO ACIDS AND SOME mRNA CODONS**

| Amino Acid | Codons | | |
|---|---|---|---|
| Alanine | GCU | GCC | GCA |
| Arginine | CGU | CGC | CGA |
| Asparagine | AAU | AAC | |
| Aspartic acid | GAU | GAC | |
| Cysteine | UGU | UGC | |
| Glutamic acid | GAA | GAG | |
| Glutamine | CAA | CAG | |
| Glycine | GUG | GGC | GGA |
| Histidine | CAU | CAC | |
| Isoleucine | AUU | AUC | |
| Leucine | UUA | UUG | CUU |
| Lysine | AAA | AAG | |
| Methionine | AUG | | |
| Phenylalanine | UUU | UUC | |
| Proline | CCU | CCC | CCA |
| Serine | UCU | UCG | |
| Threonine | ACU | ACC | ACG |
| Tryptophan | UGG | | |
| Tyrosine | UAU | | |
| Valine | GUU | | |

Three bases in a row, a codon, represent one amino acid.

The DNA of the cell's nucleus does not leave the nucleus during protein synthesis. However, protein synthesis occurs on ribosomes (Section 5:12) which are located in the cell's cytoplasm.

Different kinds of another nucleic acid, **ribonucleic acid (RNA)** (Section 3:16), are found in the nucleus, the cytoplasm, and the ribosomes. RNA is a chemical similar to DNA. But RNA contains ribose, rather than deoxyribose, as its sugar (Figure 9-9). Also, instead of the base thymine, T, it contains **uracil** (YOOR uh sihl), U. The other three bases—guanine, G; cytosine, C; and adenine, A—are the same as in DNA. RNA is often a single-stranded molecule as opposed to DNA's being double-stranded. What is the relationship between DNA, RNA, and protein synthesis? How is the DNA code passed from the nucleus to the cytoplasm? How is the code "transferred" from DNA to proteins?

RNA contains ribose and uracil. It is single-stranded.

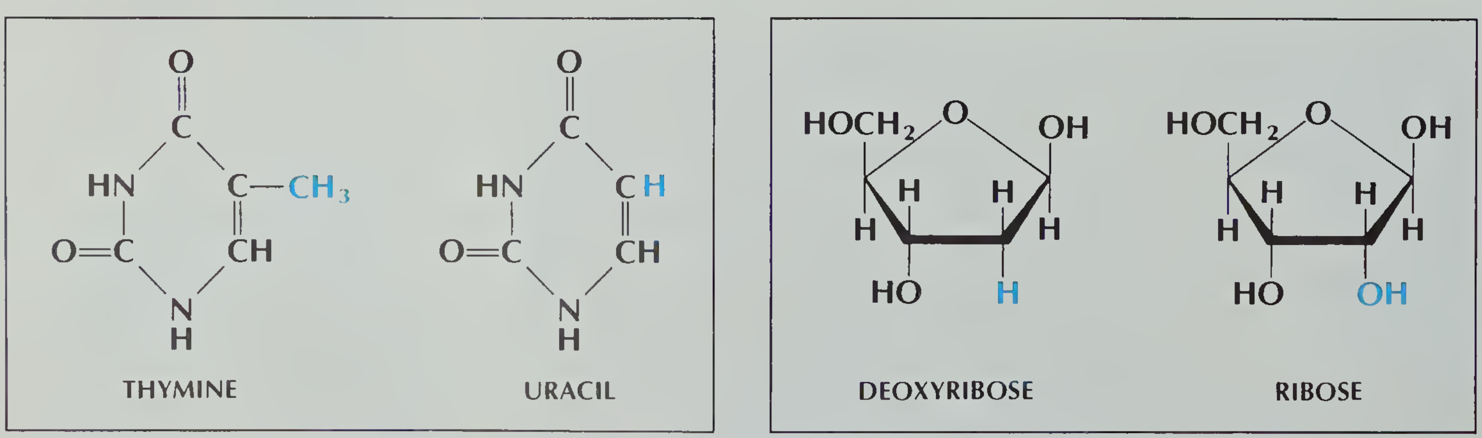


**FIGURE 9-9. Uracil has a structural formula much like that of thymine. Deoxyribose is much like ribose. Uracil and ribose in RNA take the places of thymine and deoxyribose respectively in DNA.**

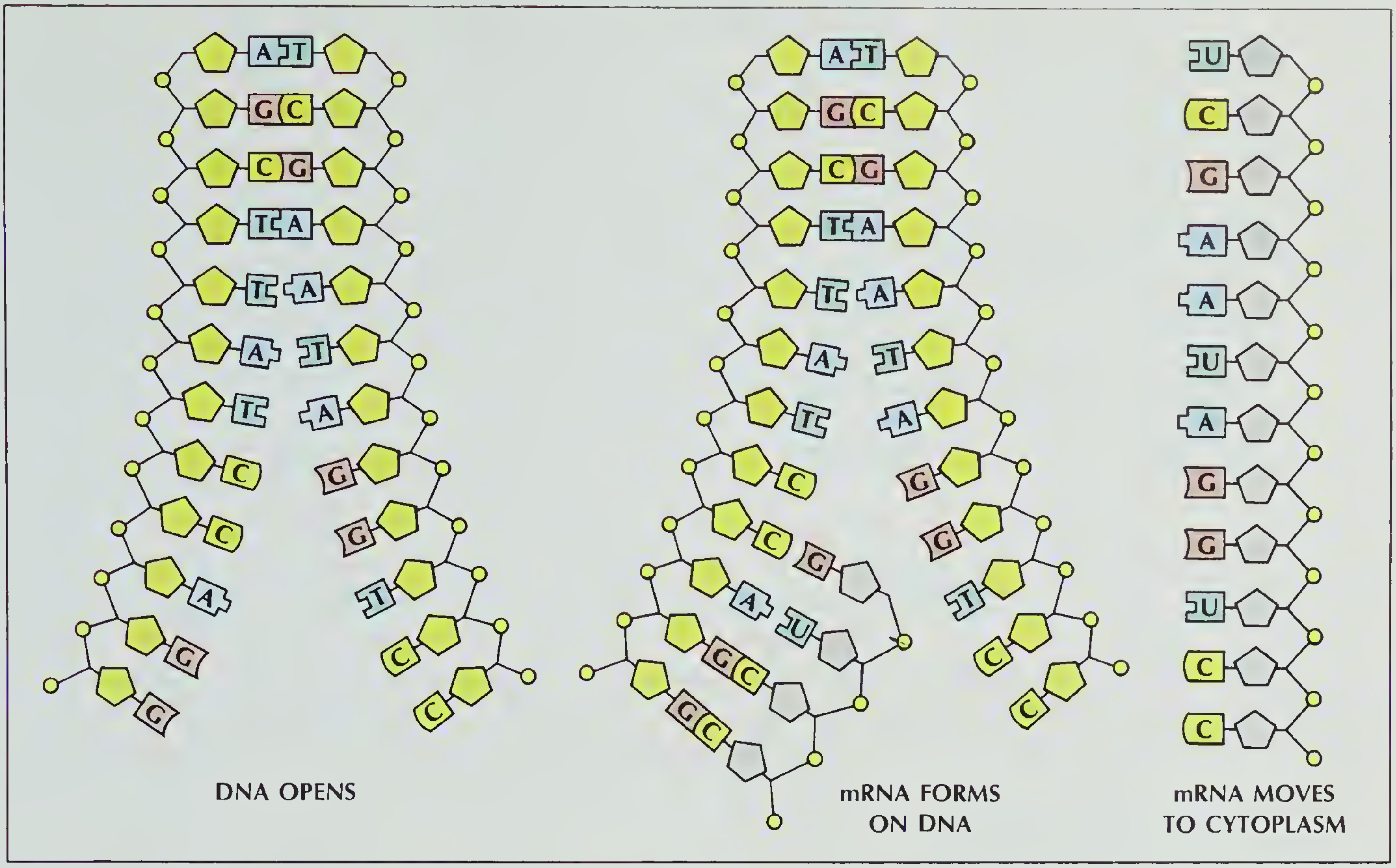


**FIGURE 9-10.** Protein synthesis begins when a DNA molecule opens. mRNA is formed on the DNA and moves to the cell's cytoplasm. The process of forming the mRNA is transcription.

## 9:7 Protein Synthesis: Transcription

Protein synthesis begins as a DNA molecule "unzips" (Figure 9-10). As the double-stranded DNA molecule unwinds, the exposed bases of one strand match up with RNA nucleotides. The RNA parts then attach to each other to form an RNA strand. After synthesis of the RNA is completed, it breaks away from the DNA strand. The two DNA strands then rejoin.

An RNA molecule is a single strand of nucleotides. *It has a specific sequence of bases determined by the sequence of DNA bases.* RNA has the code of the DNA strand from which it was made. If a DNA segment contains the nucleotide sequence AGC TTA TCC AGG, it would be changed into the RNA sequence UCG AAU AGG UCC. This sequence contains four codons. Notice that U takes the place of T in RNA. This RNA is called **messenger RNA (mRNA).** The process of transferring the code from DNA to RNA is called **transcription** (trans KRIHP shun). DNA codons are transcribed into mRNA codons.

During transcription, genetic information is transferred from DNA to RNA.

After the mRNA is made, enzymes "snip" out certain regions that are broken down. The remaining pieces of the mRNA rejoin. The mRNA then leaves the nucleus and becomes associated with the ribosomes.

## 9:8 Protein Synthesis: Translation

Certain genes produce another type of RNA called **transfer RNA (tRNA).** Each tRNA is composed of nucleotides arranged somewhat like a cloverleaf (Figure 9-11). The tRNA's combine with amino acids and bring them to the mRNA. There are as many different kinds of tRNA molecules as there are mRNA codons. *Each tRNA combines with only one type of amino acid.* One end of the tRNA molecule combines with the amino acid. This attachment requires an enzyme and ATP. The other end has a set of three exposed bases called an **anticodon.** Each type of tRNA has a different anticodon. In Figure 9-12, the tRNA's are shown as small cloverleaves with their anticodons showing.

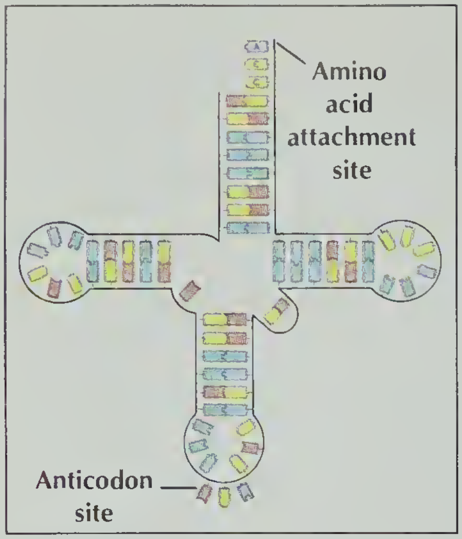


**FIGURE 9-11. Transfer RNA is a cloverleaf-shaped molecule, a single strand of RNA. tRNA molecules have different anticodons. tRNA molecules join with certain amino acids and bring them to the site of protein synthesis.**

Because tRNA anticodons fit only with specific mRNA codons, amino acids are joined in the proper sequence.

Certain mRNA codons act as "punctuation marks" which signal the end of the message.

After several copies of a protein are made, the mRNA breaks down.

When protein synthesis begins, mRNA has become associated with the ribosomes. A ribosome moves along the mRNA strand. As it does so, a tRNA molecule carrying its certain amino acid approaches. The anticodon of each tRNA molecule fits only with a certain codon of mRNA (Figure 9-12a). There is little chance for mistake because of shape requirements for joining. As another tRNA comes along, it "finds" its appropriate codon. Its amino acid links to the previous amino acid with a peptide bond. The first tRNA is then freed to work again. In this way a chain of amino acids is linked together in a specific sequence.

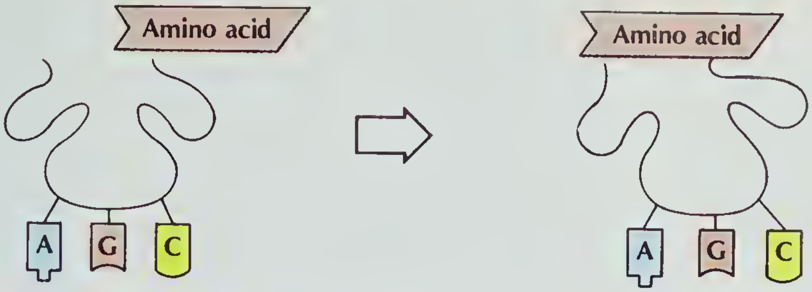
At the end of the mRNA strand is thought to be one of three codons—UAG, UAA, or UGA—which stops the message. Special tRNA molecules that carry no amino acids fit with these codons. So, there is nothing for the chain of amino acids already formed to join. The chain breaks away as a completed polypeptide or protein with a three dimensional shape. The protein is then ready for use in the cell. Several copies of a protein are made from one mRNA molecule. Then the mRNA breaks down. The interaction of mRNA, tRNA, and ribosomes to form a protein is called **translation.** Several enzymes are involved in this process.

The steps of protein synthesis do not occur one at a time. The process is rather a continuous synthesis, different parts of which may happen at once. For example, one end of the mRNA can be read while the other end of the same molecule is still being produced.

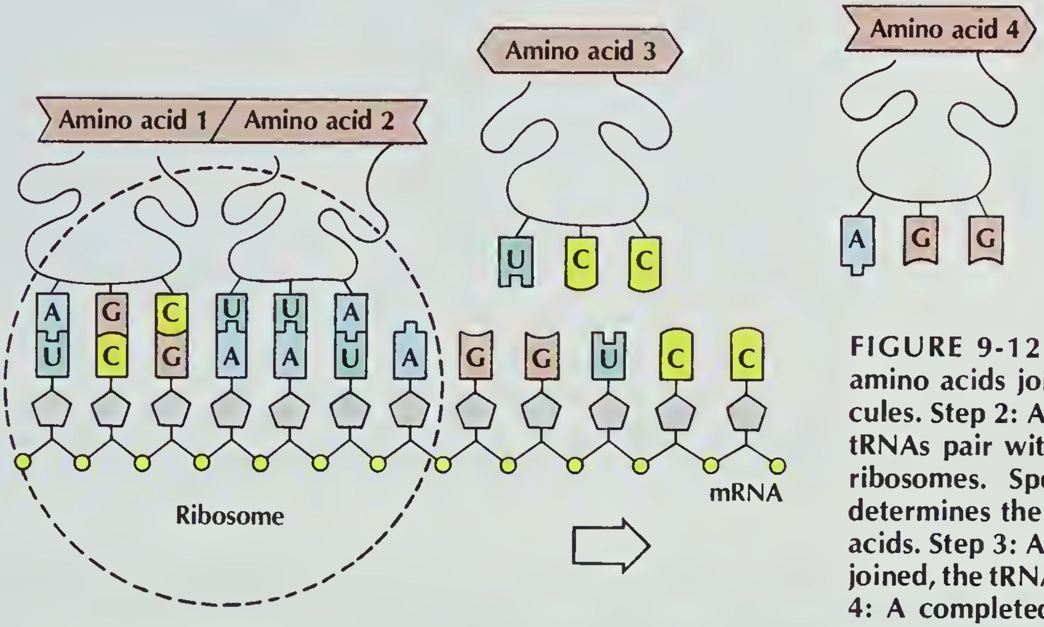
The sequence of steps during protein synthesis maintains genetic continuity.

Protein synthesis is a remarkable adaptation. The genetic code is stored in the DNA of each cell. It is replicated during each mitosis and later it is transcribed to mRNA molecules. Protein formation results from the translation of the mRNA. This process is very important in maintaining genetic continuity. The chances for mistakes are small because tRNA's only match with certain amino acids and tRNA anticodons only match with certain codons.

Knowledge about genes has increased greatly since Mendel's time. Just how far genetics has progressed is shown by the fact

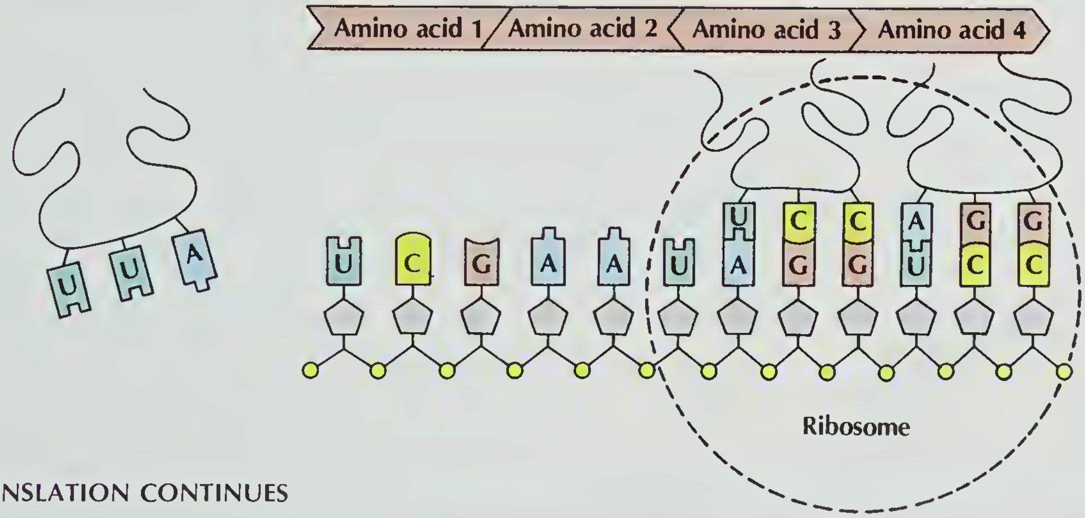

Amino acid
A
G
C
Amino acid
A
G
C

STEP 1: tRNA AND AMINO ACIDS COMBINE

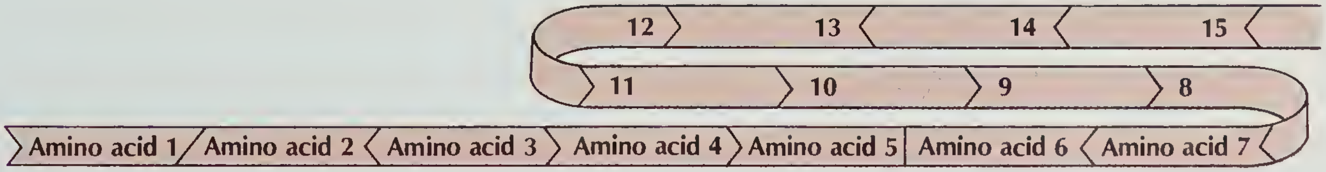

Amino acid 3
Amino acid 4
Amino acid 1
Amino acid 2
U
C
C
A
G
G
A
G
C
U
U
A
U
C
G
A
A
U
A
G
G
U
C
C
Ribosome
mRNA

STEP 2: TRANSLATION BEGINS

FIGURE 9-12. Step 1: Specific amino acids join with tRNA molecules. Step 2: As translation begins, tRNAs pair with the mRNA at the ribosomes. Specific base pairing determines the order of the amino acids. Step 3: After amino acids are joined, the tRNAs are released. Step 4: A completed polypeptide is released.


Amino acid 1
Amino acid 2
Amino acid 3
Amino acid 4
U
U
A
U
C
G
A
A
U
U
C
C
A
G
G
A
G
G
C
C
Ribosome

STEP 3: TRANSLATION CONTINUES


12
13
14
15
11
10
9
8
Amino acid 1
Amino acid 2
Amino acid 3
Amino acid 4
Amino acid 5
Amino acid 6
Amino acid 7

STEP 4: FINISHED PROTEIN OR POLYPEPTIDE FORMED that artificial genes have been synthesized. Some genes can be artificially moved around, also. More recently it has been confirmed that certain genes move around on chromosomes and from one chromosome to another naturally.

Techniques of genetic engineering are important in learning about the functions of genes.

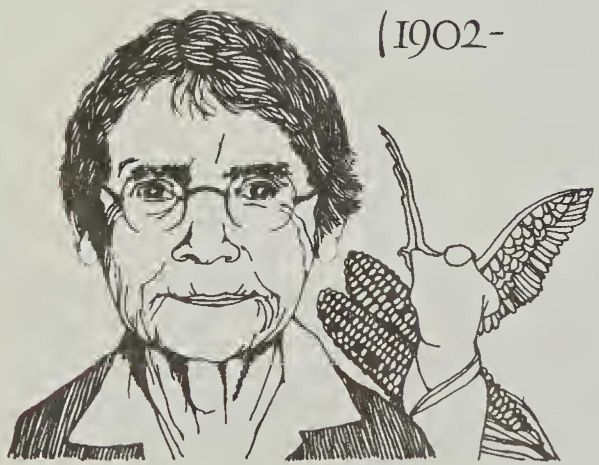
A current major area of research involves genetic engineering. **Genetic engineering** is the experimental manipulation of DNA that results in genetic recombination (Section 6:12). Using a technique of moving genes from one organism to another (often a bacterium), scientists can learn a great deal about how genes work to produce proteins and how they work with one another. This technique is discussed in Chapter 13 as an example of the importance of microorganisms to humans.

## REVIEWING YOUR IDEAS

7. Genes (DNA) control the synthesis of what other chemicals?
8. What is a codon? Anticodon?
9. Compare the structure of RNA to that of DNA.
10. Distinguish between transcription and translation.
11. Where do transcription and translation occur?
12. Distinguish between mRNA and tRNA.
13. What is genetic engineering?

## PEOPLE IN BIOLOGY

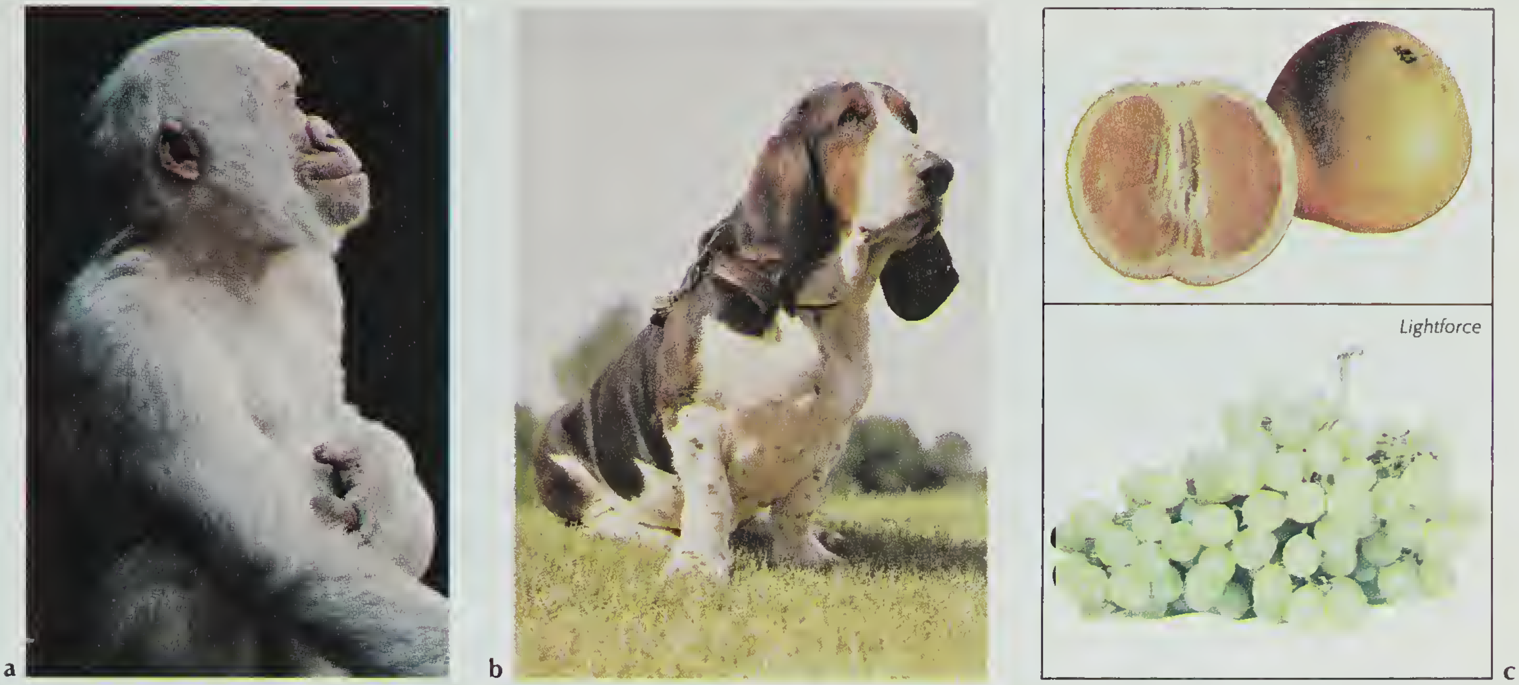
It was not until almost forty years after Barbara McClintock first discovered the "jumping gene" that the scientific community recognized its importance to genetic theory. McClintock began her research in the 1940's by studying the effects of crossing corn plants that had different kernel colors and textures. She observed kernel color patterns that could not be explained by the genetic principle popular at the time. This principle stated that genes were fixed structures laid out in a line. The results of McClintock's experiments led her to conclude that genes, instead of being fixed, move around on a chromosome, affect each other's functionings, and cause massive mutations. Scientists are just now beginning to realize how important this discovery is and how "jumping genes" bring diversity to a species.



(1902- )

Barbara McClintock

Dr. McClintock is still researching corn genetics at Cold Spring Harbor, Long Island, where she has been for the past forty years. The recognition of the importance of her discovery has led to her receiving many awards, including the National Medal of Science in 1970 and the Rosensteil Award in 1978. In 1981, she became the first Prize Fellow Laureate of the John D. and Catherine T. MacArthur Foundation.



Tom McHugh for Photo Researchers

Grant Heilman

Larry Hamill

Lightforce

**FIGURE 9-13.** (a) A white gorilla is a mutant of the normal black gorilla. (b) The legs of the bassett hound are a mutant form of the normal longer legs of dogs. (c) Seedless fruit, such as grapefruit and grapes, are mutant forms of fruit.

# EXPRESSION OF GENES

## 9:9 Mutation

The mechanisms that control the transfer of hereditary traits usually produce normal results. But, sometimes changes, **mutations,** occur. Mutations can occur as a result of changes in either chromosomes or genes (DNA).

Mutations are mistakes in the genetic message resulting from changes in either chromosomes or genes.

Chromosome mutations may occur in many ways. For example, parts of chromosomes can be dropped off or lost during crossing-over (Section 8:6) and at other times. Sometimes these "lost" parts rejoin the chromosome, but they may attach backwards or at the wrong end. Also, they may attach to the wrong chromosome. All these changes can result in abnormal information in the genetic code.

Chromosome mutations may occur during meiosis.

Changes in chromosome number also may occur. In nondisjunction (Section 8:4), gametes with extra or missing chromosomes can be formed. Sometimes a chromosome may fail to attach to a spindle fiber also resulting in abnormal gametes.

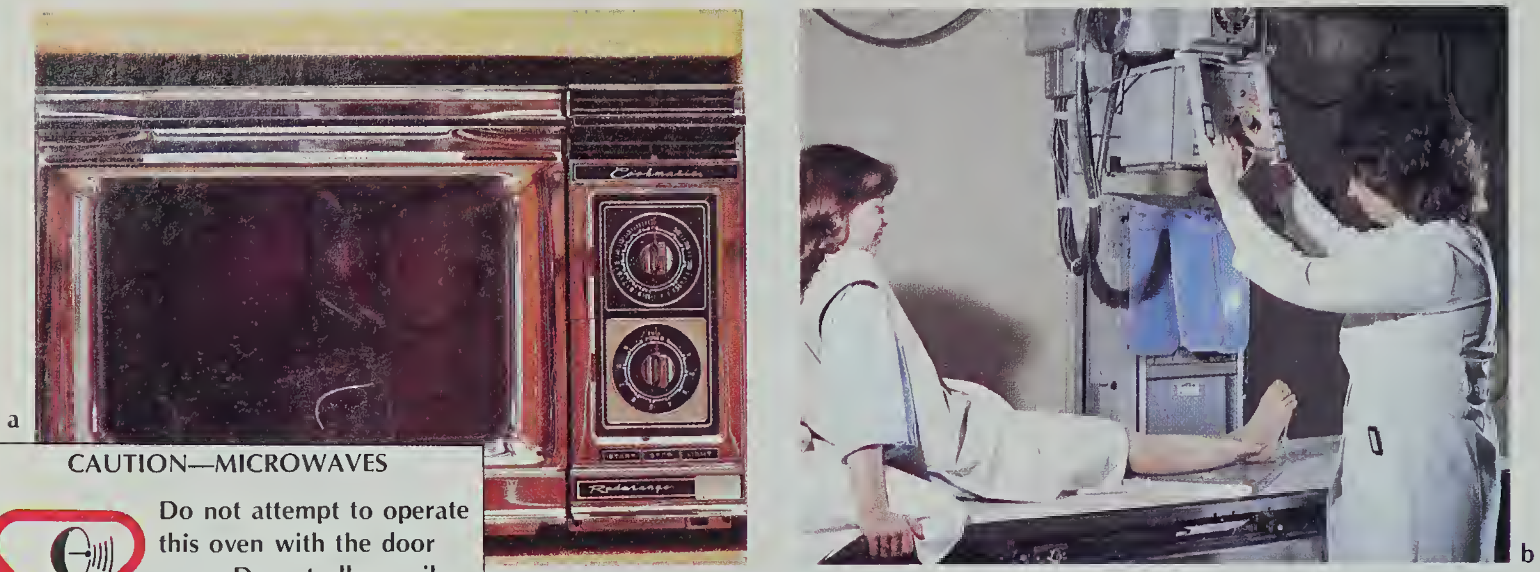
Many things result in gene mutations. Some mutations are the result of leaving out a nucleotide or adding an extra one when a new DNA strand is being built. If a nucleotide is left out or added, the remaining codons read improperly.

Gene mutations often involve the adding or leaving out of a nucleotide during DNA replication.

The rate at which mutations occur varies. A recessive allele that results from mutations causes hemophilia (Section 8:9). Such mutations occur about once in each 50 000 X chromosomes. It is estimated that in *Drosophila*, some gene mutations occur about once in 200 000 gametes. Some occur more often.

Janet L. Adams

Janet L. Adams



CAUTION—MICROWAVES

Do not attempt to operate this oven with the door open. Do not allow soil to accumulate on sealing surfaces. Consult the service manual for precautions to be taken to avoid possible exposure to extensive microwave energy.

**FIGURE 9-14.** Because radiation is a mutagen, certain precautions must be taken. (a) Microwave ovens are labeled with warnings about microwave exposure. (b) A lead apron is worn to prevent X-ray exposure of body parts other than the ankle being X-rayed.

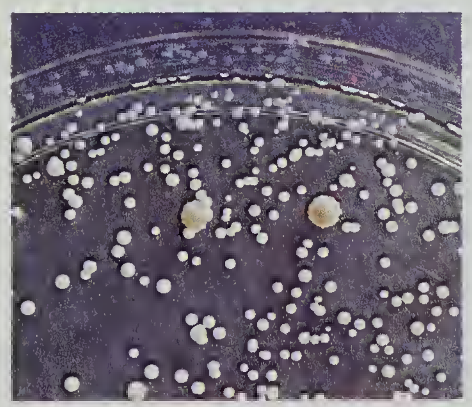
Radiation and high temperature are examples of external causes of mutations. Mutation producing agents are called **mutagens** (MYEWT uh junz). Some chemicals such as formaldehyde (for MAL duh hide) are mutagens, too. Mutagens may cause bond breaking in DNA. Mutagens can be used to increase mutation rates.

Regardless of their causes and rates, genetic mutations can be copied as if the code were unchanged. If they occur in a body cell of an organism, they are not important to the species as a whole. Why? But, mutations in the sex cells may affect an entire population of organisms because the information can be passed from one generation to the next. Will mutations be copied if they are very harmful? Explain.

Mutations arising in sex cells may spread throughout a population.

Some mutations may have little effect or even be helpful. Others may be harmful or lethal, resulting in diseases such as sickle-cell anemia, PKU, and Tay-Sachs disease (Section 8:9). Nonlethal mutations may be important for the future by providing a "storehouse of variety" for a population.

**FIGURE 9-15.** The petite mutation in yeast shows when the cells form small white colonies instead of the normal larger tan colonies. The petite mutation is a mutation in mitochondrial DNA.



Richard Brommer

## 9:10 DNA Outside the Nucleus

Most genetic information is probably transmitted according to the scheme discussed in this chapter. But, DNA in a eukaryotic cell is sometimes found outside the nucleus. Eukaryotes have organelles such as mitochondria and chloroplasts that contain DNA. This DNA is called **organelle DNA.** Also, these organelles contain mRNA, tRNA, and ribosomes and carry on some protein synthesis.

Organelle DNA is known to code for tRNAs, RNA of ribosomes, and some other substances involved in photosynthesis and cell respiration. Nuclear DNA is thought to control the synthesis of the outer protein part of these organelles, proteins of ribosomes, and enzymes needed for organelle protein synthesis. Things made in the cell cytoplasm from nuclear DNA instructions can migrate into the organelles.

## 9:11 DNA and Genetics

Knowledge of DNA and protein synthesis can be related to ideas of genetics.

What you have learned about DNA and protein synthesis can explain some ideas of genetics. As an example, consider flower color in a plant. Red flowers *(R)* are dominant to white flowers *(r)*. Plants having the genotype *RR* or *Rr* will be red. Plants with the genotype *rr* will be white. How can these patterns be explained?

Genes are DNA, and DNA codes for specific proteins. Suppose the *R* allele (DNA) carries a code that directs the synthesis of a particular enzyme. (Enzymes are proteins.) That enzyme converts a substance in the cells of flowers to a red pigment. The *r* allele (DNA) is a mutant form of the *R* allele. Its nucleotide sequence (and so its code) is slightly different. Because of the difference, the enzyme needed to make red pigment is not produced properly. Thus, a flower which is *RR* or *Rr* will be able to make the red pigment. Its phenotype will be red. But an *rr* flower cannot make any pigment. Its phenotype will be white.

Phenotypes result from the combination of proteins produced by a given set of alleles.

Phenotypes are really the results of *which* enzymes (or other proteins) are produced by certain combinations of alleles. All phenotypes have a chemical basis. An organism is a set of thousands of phenotypes, each of which is based on the synthesis of proteins. Not all the phenotypes that an organism has can be seen. The presence of some, such as type B blood or abnormal hemoglobin, can be determined in ways other than by *seeing* the phenotype.

## 9:12 A Genetic Control System

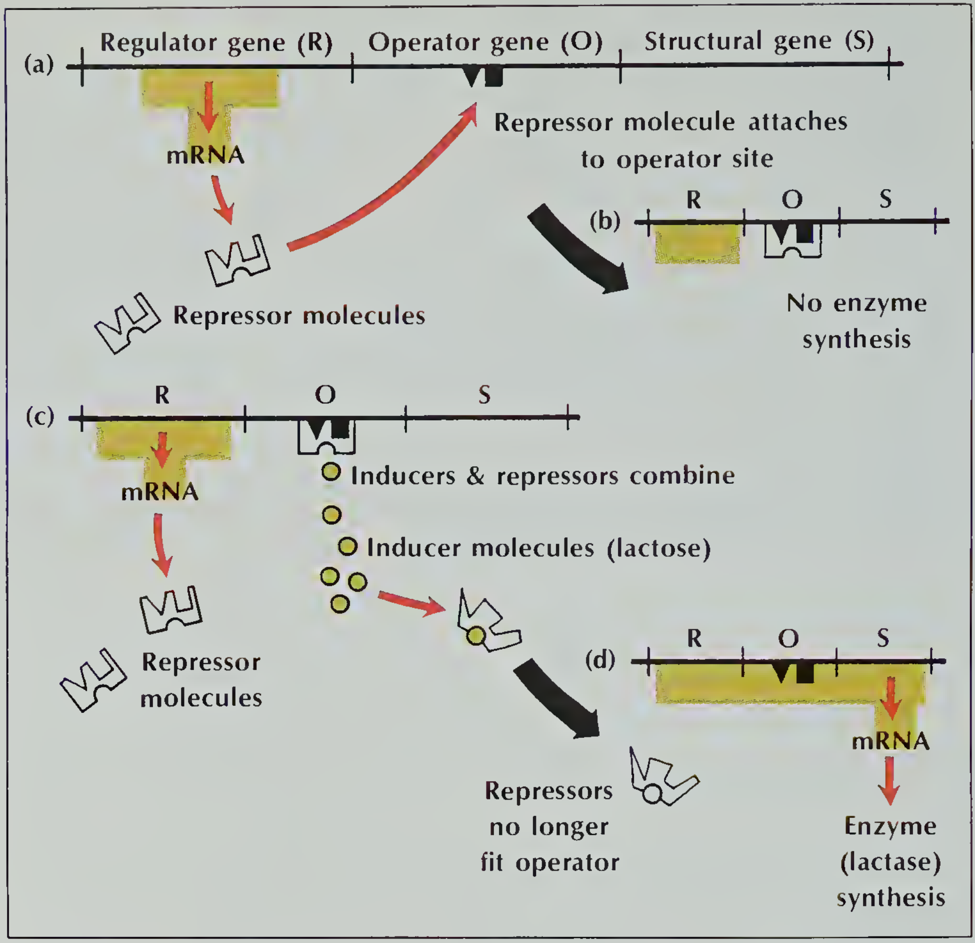
What is a gene? The study of protein synthesis shows one way to define a gene—part of a DNA molecule that directs the synthesis of a protein or polypeptide. This type of gene is called a **structural gene.** You know that genes cannot all be making proteins all the time. What controls when genes are active? What controls which proteins are made within cells at certain times?

Structural genes direct the synthesis of proteins.

Much of the current knowledge of genes comes from research with bacteria, prokaryotic cells (Section 5:12). These cells have no true nuclei but they do have DNA like the DNA of eukaryotic cells. Studying of bacteria shows that several types of genes exist for these cells. Some genes control the synthesis of proteins by structural genes. Therefore, they are called **regulator genes.** Like structural genes, regulator genes synthesize mRNA. The mRNA in turn synthesizes special proteins called **repressors.** Repressors determine whether a structural gene will synthesize a protein or not.

Regulator genes produce repressors which control the activity of structural genes.

**FIGURE 9-16.** (a) When no inducer is present, (b) repressor molecules bind to the operator gene and prevent synthesis of the enzyme. (c) When inducer molecules are present, they combine with the repressor. (d) Thus, the operator gene is not blocked and the mRNA specific for making the enzyme is produced.


(a)
Regulator gene (R)
Operator gene (O)
Structural gene (S)
mRNA
Repressor molecule attaches to operator site
Repressor molecules
(b)
R
O
S
No enzyme synthesis
(c)
R
O
S
mRNA
Inducers & repressors combine
Inducer molecules (lactose)
Repressor molecules
(d)
R
O
S
mRNA
Repressors no longer fit operator
Enzyme (lactase) synthesis

In enzyme induction, a substrate causes a cell to begin making the enzyme associated with it.

Bacteria called *E. coli* thrive on a culture medium containing glucose. Glucose is their normal energy source. Therefore, the cells constantly produce the enzymes needed to break down glucose. Lactose, a disaccharide, is not normally used as an energy source. The bacteria can be grown on a culture medium with lactose instead of glucose. The bacteria begin to produce the enzyme lactase. Lactase enables the cells to convert lactose to monosaccharides which can be broken down. The monosaccharides can then be used as energy sources. This process in which a substrate (lactose) entering a cell causes the cell to begin producing an enzyme is called **enzyme induction.** The chemical causing induction is an **inducer.** If lactose is removed, lactase production stops.

Repressors may combine with the operator genes, blocking the synthesis of an enzyme.

Enzyme induction depends on regulator genes and repressors. The regulator genes synthesize repressors. The repressors, in turn, combine with a region of DNA called the **operator gene.** The operator is located ahead of the structural gene for lactase. This blocks the enzyme which "unzips" the DNA of the structural gene. Thus, no mRNA can be formed and no lactase can be produced. However, when lactose enters the cell, it combines with the repressor molecule and changes its shape. Then the operator is no longer blocked, mRNA can be formed, and lactase can be produced (Figure 9-16).

What is the advantage of enzyme induction? It results in the production of certain enzymes *only when they are necessary.* In this way, the cell conserves both materials and energy by not producing unnecessary enzymes. Research with other enzymes and with other prokaryotes shows that enzyme induction is common. But, various other control systems have been described for prokaryotes.

Control systems other than enzyme induction also exist in prokaryotes.

## REVIEWING YOUR IDEAS

14. What is a mutation?
15. Where is most of a cell's DNA located? Where else is it found?
16. How is DNA related to the expression of a phenotype?
17. Distinguish between a structural gene and a regulator gene in a bacterium.

## ADVANCES IN BIOLOGY

## 9:13 Genetic Control in Eukaryotes

With the discovery of gene regulation systems in prokaryotes, biologists assumed similar systems would be found in eukaryotes. It is now known that gene control in eukaryotes is much more complex. As in prokaryotes, the activity of eukaryotic genes seems to depend upon the presence or absence of different chemical substances. Several events being studied occur between a gene and expression of its product.

DNA in eukaryotes has both more and more kinds of proteins bound to it than does DNA in prokaryotes. Most likely some of those proteins are involved in gene regulation, probably at the level of transcription (Section 9:7). (This control is the major kind that occurs in prokaryotes.) Most of the protein molecules bound to eukaryotic DNA are histones. Histones are very basic proteins that play an important role in chromosome structure. However, they probably do not take part directly in gene control. Other proteins (non-histone proteins) are present in smaller amounts and are suspected to be very important in gene activity. In controlling transcription a protein may inactivate a gene by binding to it. Another protein may expose the gene and make it active by removing a bound protein. Certain chemical regulators, hormones, affect cells by "switching on" genes (Section 29:8). It is known that hormones bind to specific sites on DNA, probably directly to proteins located at those sites.

Certain proteins are suspected to be involved in eukaryotic gene control.

The presence of methyl groups bonded to DNA seems to affect gene activity. A **methyl group** is a carbon atom bonded to three hydrogen atoms ($-CH_3$). For reasons that are not yet understood genes that have more such groups seem to be more active in transcription. Inactive genes may become active by the

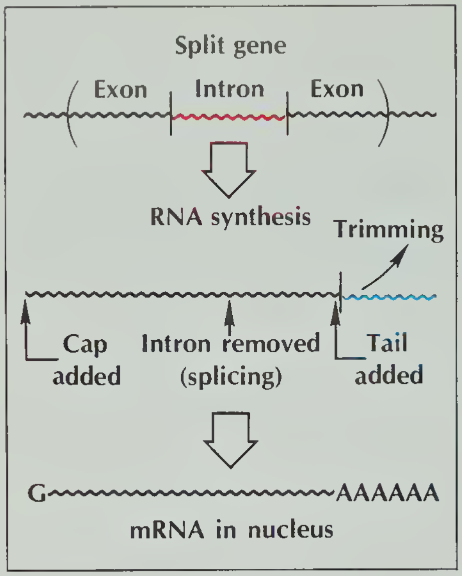


**FIGURE 9-17.** Splicing, capping, and tailing of mRNA are events which can be involved in gene expression in eukaryotes. These events occur in the cell nucleus.

addition of methyl groups, a process called **methylation**. Or, active genes may become inactive by their removal. Some researchers propose that methyl groups affect gene activity by changing the structure of the DNA. Others suggest that they determine which proteins bind to DNA or how tightly they bind.

Whether or not a gene is active, there are events after transcription is completed that can determine if the product of the gene is made. These events are called "post-transcriptional" events. One class of such events occurs in the nucleus and is called **RNA processing**. mRNA differs from other RNA molecules in certain ways. For example, at one end of the mRNA there is a guanine "cap." At the other end of the mRNA is a long "tail" of adenine molecules. The cap and tail are added in the nucleus after the RNA is made. These changes of the RNA seem to make it bind more easily to ribosomes and be more stable. The functional mRNA is also much shorter than the RNA originally made in the nucleus. Extra parts at the beginning and end are removed in the nucleus in a process called trimming. The pieces of RNA removed are usually unstable and are broken down.

Many genes of complex organisms are called **split genes**. They contain sections of DNA called **exons** that contain the information that codes for the protein product of the gene. RNA copies of exons are present in the mRNA. In split genes, however, the exons are separated by other DNA sequences called **introns** that do not code for the protein. Transcription of a split gene produces a long RNA molecule in the nucleus that contains copies of exons and introns. There are enzymes in the nucleus that remove the RNA copies of introns and splice together the exons so that the continuous set of exon information needed to make the protein is formed. If splicing does not occur properly, mRNA will not form and the gene will not be expressed.

Proper splicing can control gene expression.

Even after the exons are spliced together and cap and tail added, the mRNA cannot be used for protein synthesis until it is moved from the cell nucleus to ribosomes in the cytoplasm. Very little is known about the steps required to move the mRNA. It is clear that new mRNA in the cytoplasm is associated with proteins. It is likely that those proteins are involved in the transport process.

In most growing cells, once mRNA reaches the cytoplasm, it is used for protein synthesis. However, in some cell types, RNA molecules are stored in the cytoplasm for use later. Stored or "masked" messages are coated with proteins and remain in the cytoplasm until they are "unmasked." The existence of masked messages was first discovered in frog eggs and has been studied there in detail. In egg cells, masked messages can last for years.

Some messages are "masked" for years in the cytoplasm.

After the protein product is made, there are still a number of steps where the product's function can be controlled. Some proteins carry out reactions that occur in a different place in the cell from where they are made or even outside that cell. These proteins must move to their places of action and that movement involves crossing one or more membranes. Most of these proteins are made with extra amino acids that help them cross membranes. The extra amino acids are removed.

Many proteins require the post-translational addition of other chemicals, such as sugars. Sugar molecules are added to proteins in Golgi bodies. Finally, many proteins require activation as a final step.

In this section you see that there are many control steps between a gene and the expression of its phenotype in eukaryotes. They include control of transcription, RNA processing, RNA transport, translation and protein processing and movement. Not all of these control steps are unique to eukaryotes. Bacteria do not, however, have split genes, do not "cap" and "tail" their mRNAs, and do not have to transport mRNA from the site of transcription to the site of translation. A great deal more must be learned about the details of each type of regulation and how all the types work together. Many researchers throughout the world have devoted their lives to unraveling these complex processes.

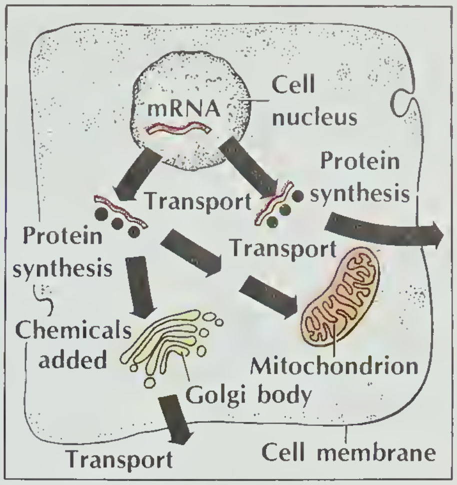


**FIGURE 9-18. Genetic control in eukaryotes occurs at many levels between a gene and the expression of its product in a phenotype. These events include transport of mRNA out of the nucleus, RNA unmasking, protein movement to site of action, and addition of other chemicals.**

## CHAPTER REVIEW

### SUMMARY

1. DNA was discovered in 1871. However, its role as the genetic message was not suspected until Griffith's experiments.
2. Watson, Crick, and Wilkins developed the double helix model of DNA in 1953. The "ladder" in this model has uprights composed of alternating sugars and phosphates. The rungs are pairs of nitrogen bases.
3. During DNA replication, the strands of the helix make new strands. Each new molecule contains one original strand of DNA and one new strand.
4. Many proteins are enzymes that control a cell's chemistry. Other proteins may have other functions.
5. Genes code for synthesis of proteins or polypeptides. In this way, genes determine a cell's features.
6. DNA is a genetic code. Bases in groups of three, codons, code for specific amino acids.
7. During transcription, the DNA code is transcribed into messenger RNA. During translation, transfer RNA molecules bring specific amino acids to the messenger RNA on the ribosomes. There the amino acids are assembled in the proper sequence to form a polypeptide or protein.
8. Mutations, genetic changes, may occur in both genes and chromosomes. Some may occur during replication. Others are caused by external factors. Mutations can be harmless, but often they are harmful or lethal.
9. Organelles such as mitochondria and chloroplasts contain DNA and the machinery necessary for protein synthesis. They are known to synthesize certain compounds.
10. Phenotypes result from the synthesis of certain proteins.
11. Study of bacteria (prokaryotes) has shown that enzyme induction can occur and that structural, regulator, and operator genes are present. There are other systems of gene control in prokaryotes, and eukaryotes have different systems, too.

12. Gene control in eukaryotes involves a variety of events. Expression of genes may be regulated during transcription, before mRNA leaves the nucleus, or after a protein has been synthesized.

## LANGUAGE OF BIOLOGY

anticodon
bacterial transformation
codon
DNA
enzyme induction
exons
inducer
messenger RNA
methylation
mutagen
mutation
nucleotide
operator gene
organelle DNA
regulator gene
replication
repressor
split genes
structural gene
transcription
transfer RNA
transforming principle
translation

## CHECKING YOUR IDEAS

*On a separate paper, match each phrase from the left column with the proper term from the right column. Do not write in this book.*

1. organelle where protein synthesis occurs
2. has an anticodon
3. genetic mistake
4. transcription occurs in this cell part
5. represents an amino acid
6. contains nonnuclear DNA
7. carries DNA code to ribosomes
8. material of which genes are made
9. four kinds in DNA
10. later discovered to be DNA

a. codon
b. DNA
c. mitochondrion
d. mutation
e. mRNA
f. nucleotide
g. nucleus
h. ribosome
i. transforming principle
j. tRNA

## EVALUATING YOUR IDEAS

1. How did Griffith explain that living, smooth *Pneumococcus* cells were in the blood of mice?
2. How was Griffith's hypothesis tested? What control was used?
3. What is a model? What facts did Watson and Crick hope to explain by constructing a model of DNA? Did they succeed?
4. Sketch a segment of a molecule of DNA which is six base-pairs long. Show how this segment of a DNA molecule probably replicates.
5. What happens to DNA during interphase? Why is this process necessary? What would happen during mitosis if this process did not occur?
6. Genes direct the synthesis of what kind of large molecules?
7. Why is a codon composed of three nucleotides? What does a codon represent?
8. Using the DNA model of question 4, assume that one strand of the segment served as a pattern for the formation of a segment of a molecule of mRNA. Sketch the segment of the mRNA molecule that would be formed. What information would be contained in this segment of mRNA?
9. How many kinds of tRNA molecules are there? Why?
10. By using diagrams, describe the translation phase of protein synthesis.
11. A certain protein is composed of 1500 amino acids. How long is the gene responsible for its synthesis?
12. How are gene mutations caused? How can a mutation be passed to future generations?
13. How can chromosome mutations occur?
14. Why are mutations which occur in a body cell of an organism not important to the entire species? How may mutations in the sex cells be important to the entire species?

## CHAPTER REVIEW

15. Give examples of DNA located outside the nucleus. What are some functions of organelle DNA?
16. A certain bacterium normally does not use sucrose. However, if sucrose is available it begins to manufacture the enzyme sucrase. How is this process controlled? How is it adaptive?
17. Explain several ways in which genes of eukaryotes are controlled.

## APPLYING YOUR IDEAS

1. Suppose a gene contains the code for synthesis of an enzyme. During replication of the gene a mutation occurs so that one of the nucleotides is left out. Will the enzyme produced more likely be close to "normal" if the deleted base occurs near the beginning or the end of the gene? Explain.
2. How does the knowledge that mitochondria and chloroplasts have their own DNA systems support a hypothesis that these organelles might actually be descendants of what were once free-living organisms?
3. In a certain flower, the genes red, *R*, and blue, *r*, are incompletely dominant. The heterozygous condition produces purple flowers. Using your new knowledge of DNA and protein synthesis, explain why:
   (a) the genotype *RR* produces red flowers
   (b) the genotype *rr* produces blue flowers
   (c) the genotype *Rr* produces purple flowers
4. A dominant allele results in the production of normal hemoglobin. The recessive allele results in abnormal hemoglobin. Using your knowledge of sickle-cell anemia, predict what the red cells of a heterozygous person would look like.

## EXTENDING YOUR IDEAS

1. Build a set of models to represent a DNA molecule, the mRNA made from it, several tRNA molecules, and amino acids. Use the model to illustrate the process of protein synthesis.
2. Maurice Wilkins used X–ray diffraction to analyze the shape of the DNA molecule. Learn about this technique.
3. The experiments of Meselson and Stahl and of Taylor, Woods, and Hughes established that DNA replicates according to the Watson-Crick hypothesis. Both experiments made use of isotopes. Prepare a report on each of these experiments and explain how they verified the hypothesis.
4. Prepare a report on radiation as a cause of mutation.
5. Certain strains of *Paramecium aurelia* exhibit a "killer" trait. This trait seems to be determined by cytoplasmic rather than nuclear inheritance. Using library resources, research and prepare a report on this phenomenon.

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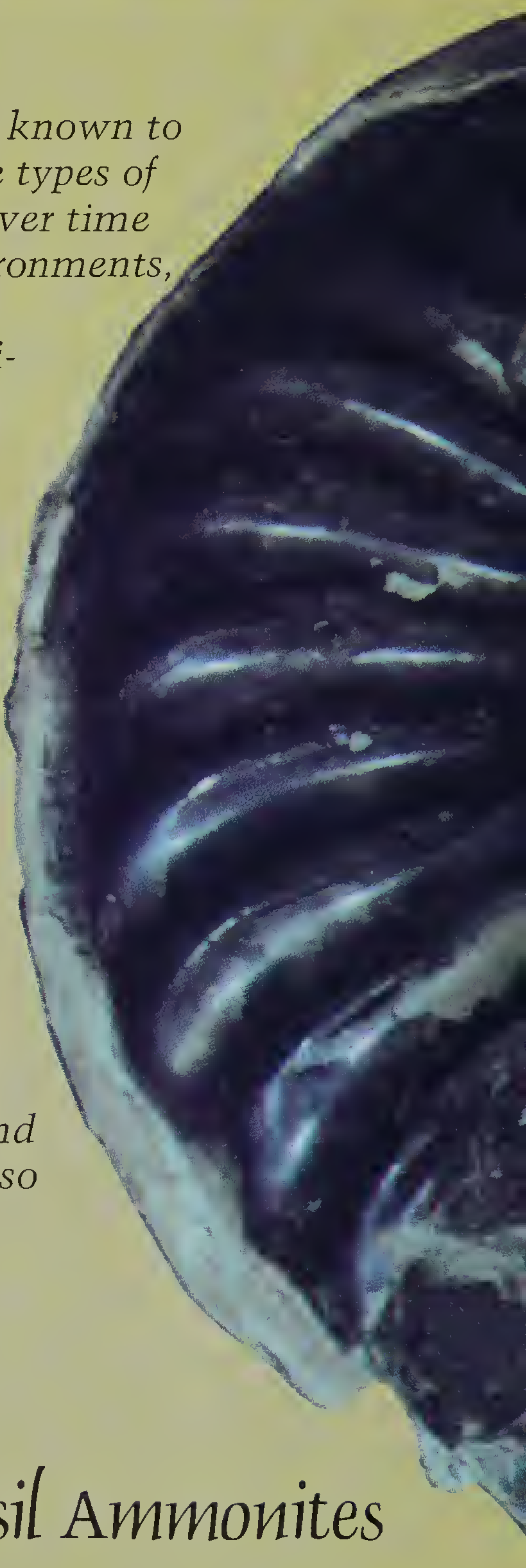
# CHANGES

*Nearly two million kinds of organisms are known to live on Earth today. However, these same types of organisms have not always lived here. Over time environments have changed and with changing environments, the types of organisms have changed.*

*Organisms must be adapted to their environments or they may become extinct. Shown here are fossils of ammonites, sea animals that lived about 150 million years ago. These fossils were found in southern England, which at that time was covered by warm seas. Ammonites were once well adapted to their environment but after their environment changed, they became extinct. Information about them comes from study of their fossils and from study of their present-day relatives, squids and nautiluses.*

*How did living things originate? What has caused the changes among some organisms and the extinction of others? What information do we have about organisms no longer living? Biologists attempt to answer these and related questions using scientific methods. In Unit III, you will study some of the evidence that has been gathered and some of the conclusions that have been made. You also will study how living things are classified.*



Fossil Ammonites

# Unit III

Robert E. Pelham and William J. Tiffany

Larry Agenbroad/Hot Springs Mammoth Site, SD

*Fossils are remains or evidence of things which were once alive. They can be found in almost every part of the world. Special techniques are used to dig up and preserve these remains for study. Here, workers in South Dakota are digging up the remains of mammoths. Mammoths are animals that lived several thousand years ago and resemble elephants. How is the age of a fossil determined? What kinds of information are obtained from fossils?*

Chapter

10

# CHANGE WITH TIME

The earth is thought to be nearly five billion years old. Biologists estimate that life first appeared on Earth more than three billion years ago. Both the earth and the organisms inhabiting it have changed during that time. The change in organisms over a period of time is called **evolution.**

Different explanations have been given to explain how evolution occurs. Some of these explanations will be studied later in this chapter. First, it is helpful to study evidence that living things change.

**GOAL:** You will gain an understanding of evolution (changes in living things) and the evidence supporting the theory of evolution.

The theory of evolution is the most widely accepted scientific explanation of the origin of life and changes in living things. You may wish to investigate other theories.

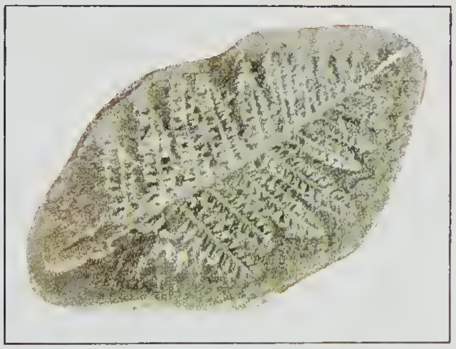
## EVOLUTION: EVIDENCE

### 10:1 Fossils: Formation and Dating

Any part of or trace of a once living organism is called a **fossil.** A fossil may be all, part, or an imprint of an organism. Some entire organisms have been found frozen in ice or enclosed in amber. But this type of fossil is rare. When most organisms die, they are quickly decomposed (Section 1:4), so no record of their life is left. In order for a fossil to form, something must happen to prevent the organism or part of it from decaying. A hard part of an organism, such as a bone or a tooth, may be preserved if it is surrounded and compressed by clay or sand soon after the organism dies. The surrounding sediments prevent decomposition. Then, as the sediments turn to rock over long periods of time, the part of the organism is preserved.

Fossils formed in sedimentary rock are the most common fossils. Sedimentary rocks form by particles settling on top of each other. Layers of the particles are built up. When the layers

**FIGURE 10-1. The impression of a fern leaf in rock is a fossil formed when the leaf is pressed into mud that hardens. The leaf decomposes leaving the impression.**



*University of Houston*

Frank Balthis

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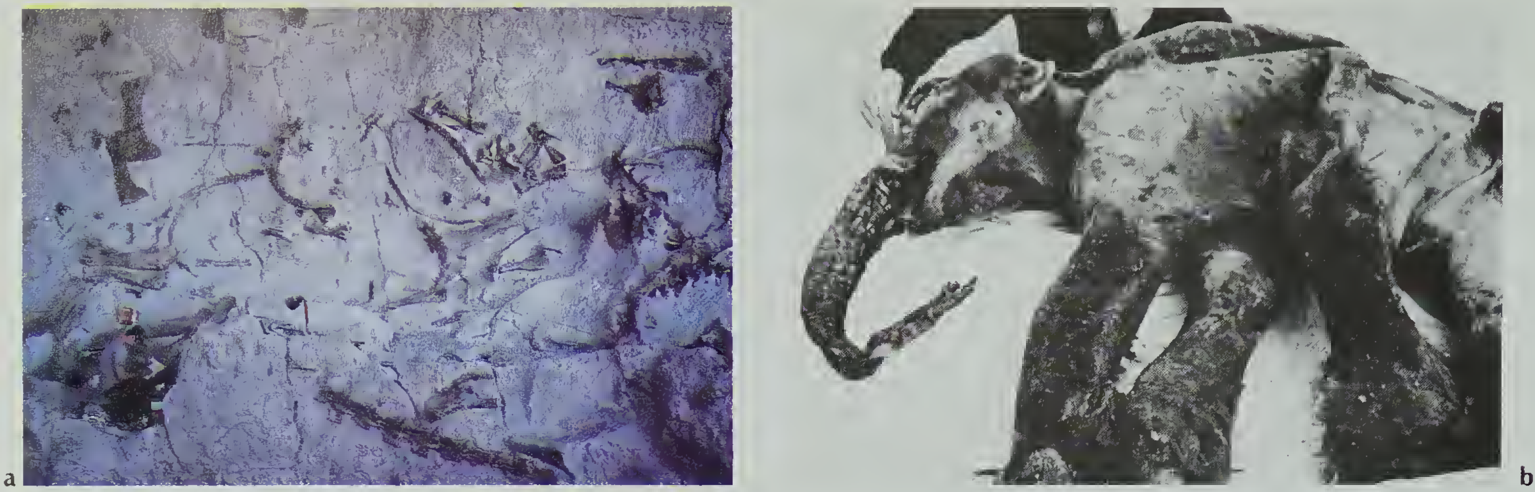
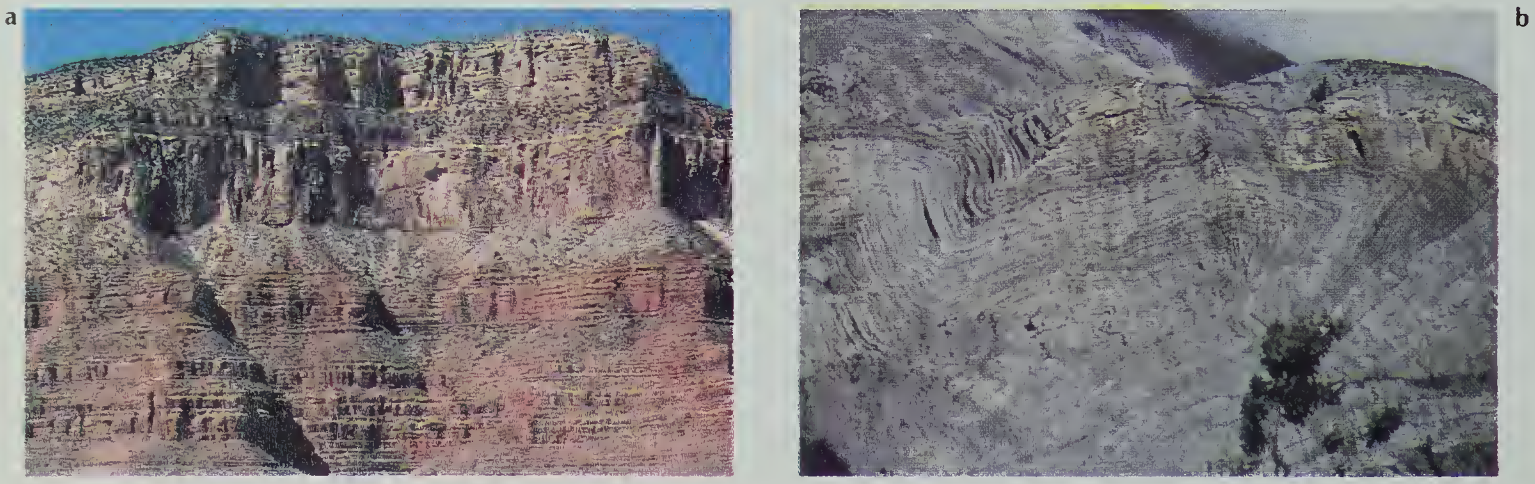


**FIGURE 10-2. Parts of animals and whole animals have been found preserved. (a) Bones of dinosaurs and other animals have been uncovered in excavations at Dinosaur National Monument, Utah. (b) This baby mammoth was unearthed from frozen ground in the Magadan territory of Russia.**

are undisturbed, the lower layers are the oldest and the upper layers are the newest. As an analogy think of this situation. If you stacked up newspapers adding the current paper each day to the top, as long as the stack was undisturbed, the oldest paper would be on the bottom and the newest paper would be on the top. Fossils found in undisturbed lower layers of rock are of organisms older than those whose fossils are found in upper layers. The relative time of appearance and disappearance of many organisms can be determined from this layering.

There are more accurate methods of dating organisms. These methods are based on the use of isotopes. Recall that isotopes (Section 3:2) are atoms that differ in the number of neutrons they have. Some isotopes have unstable nuclei and are called **radioactive isotopes.** The unstable nuclei break down and give off particles. You may be familiar with Geiger counters. Geiger counters are instruments that detect those particles. Energy is also given off. When radioactive isotopes decay, matter changes to energy at known rates. The **half-life** of an isotope is the time needed for one half of the radioactive material to decay. Carbon 14 is a radioactive isotope with a half-life of 5730 years. After 5730 years, half of an original carbon-14 sample will have changed to energy.

Half-life is the time necessary for one half of a radioactive sample to disintegrate.



Michael Collier

Larry Roberts

**FIGURE 10-3. (a) Undisturbed sedimentary rock shows flat layers of deposits. Fossils found in lower layers of undisturbed sedimentary rock are older than fossils found in top layers. (b) When sedimentary rock is disturbed, age of fossils is sometimes harder to determine.**

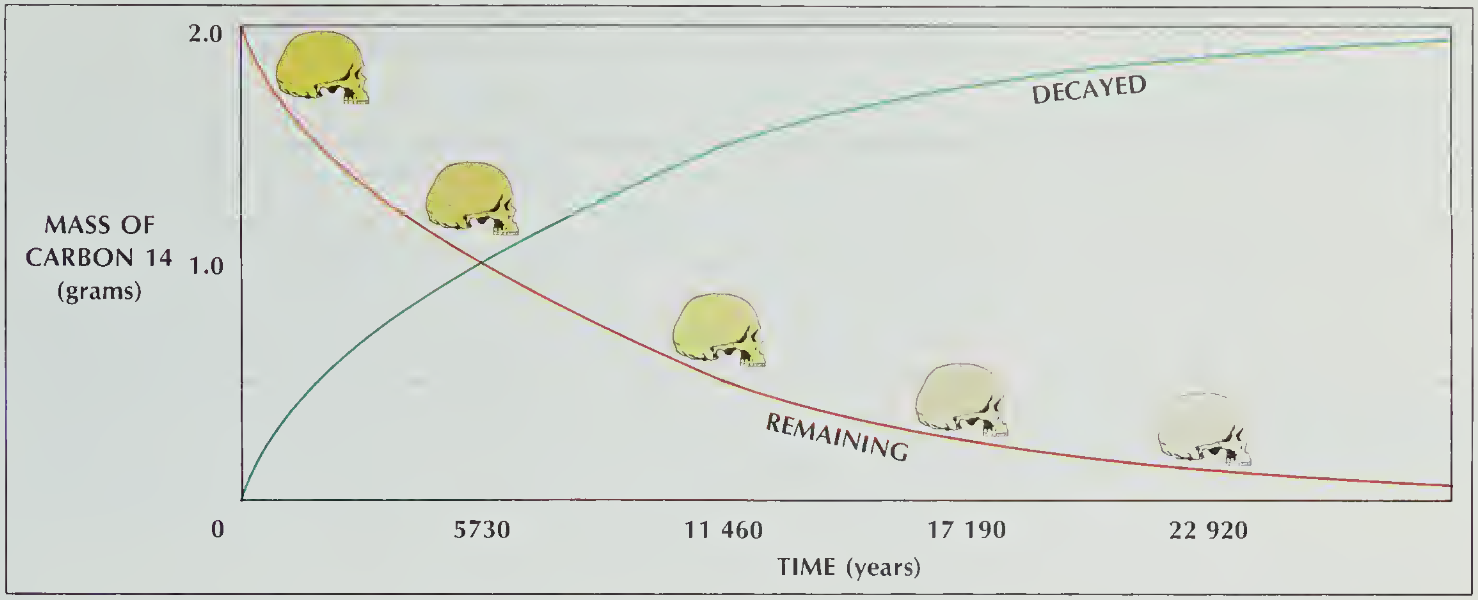


**FIGURE 10-4.** Radioactive decay of carbon 14 is the principle behind radiocarbon dating. The age of a fossil is determined by comparing amounts of carbon 14 present in living organisms with the amount remaining in the fossil. For example, if a fossil contained 0.5 g carbon 14 and living specimens contained 2 g, the fossil would be about 11 460 years old. In this time three-fourths of the carbon 14 decayed.

All living things contain some radioactive isotopes. During photosynthesis, plants take in radioactive carbon from the air. The carbon is in the form of $^{14}CO_2$. This carbon enters all organisms through food chains (Section 1:4). A given mass of living tissue contains a certain amount of radioactive carbon. Scientists compare the amount of radioactive carbon remaining in a fossil with the amount in the same mass of living tissue today. By using the half-life, they can approximate the age of the fossil. This method is known as radiocarbon dating and gives results valid for fossils up to about 20 000 years old.

Ages of older fossils can be estimated by studying surrounding rock samples for other radioactive elements such as uranium and potassium. These elements have a much longer half-life than carbon 14. Thus, they can be used for dating fossils millions of years old.

Some fossils can be dated by studying radioactive decay in rock samples.

*Teledyne Isotopes Radiocarbon Laboratory*

**FIGURE 10-5.** In the process of radiocarbon dating, carbon dioxide gas is purified in this apparatus prior to its analysis for carbon-14 content.

## 10:2 Fossil Record: Interpretation

Earth's history can be divided into **eras** and subdivided into **periods.** Table 10-1 gives a brief account of the earth's history and the major life forms of each period. Much information about life in the past comes from the fossil record.

What general facts come from the study of fossils? Many fossils give information about types of organisms no longer living on Earth. Such organisms are said to be **extinct.** Extinct organisms are studied in terms of what is known about the environment at the time and place the organisms lived. It seems that organisms were adapted to their environments. But, environments change. If a kind of organism is to survive, it must "fit" the new environment. Many organisms did not "fit," so they became extinct.

In order to survive in a changing environment, organisms must adapt.

**TABLE 10-1. GEOLOGIC TIMETABLE AND MAJOR LIFE FORMS**

| Era | Period | Epoch | Age (years ago) | Representative Life Forms |
|---|---|---|---|---|
| CENOZOIC | Quaternary | Recent | 100 000 | Humans; modern forms of plants and animals |
| | | Pleistocene | 1 000 000 | Extinction of many mammals; primitive humans; grasslands |
| | Tertiary | Pliocene | 10 000 000 | Early humans; other mammals; herbs |
| | | Miocene | 30 000 000 | Mammals; grasses |
| | | Oligocene | 40 000 000 | Primates and other mammals; forests common |
| | | Eocene | 60 000 000 | Primitive horse; other mammals; flowering plants |
| | | Paleocene | 75 000 000 | Mammals predominant; more modern flowering plants |
| MESOZOIC | Cretaceous | | 135 000 000 | Extinction of giant reptiles; birds and insects; flowering plants |
| | Jurassic | | 165 000 000 | Dinosaurs dominant; primitive birds and mammals; earliest flowering plants |
| | Triassic | | 205 000 000 | Dinosaurs and other reptiles; early mammals; primitive seed plants |
| PALEOZOIC | Permian | | 230 000 000 | Rise of insects; early reptiles |
| | Carboniferous | | 280 000 000 | Insects and amphibians; mosses and ferns |
| | Devonian | | 325 000 000 | Age of fishes; early amphibians; early bryophytes; ferns |
| | Silurian | | 360 000 000 | Club mosses; insects and other invertebrates |
| | Ordovician | | 425 000 000 | Primitive mollusks and fish; algae |
| | Cambrian | | 500 000 000 | Protists; sponges; jellyfish; spore-producing plants |
| PRECAMBRIAN | | | 5 000 000 000 | Monerans; simple protists; fungi; simple invertebrates |

Studies of fossils also indicate that older organisms (found in lower layers) are generally less complex than newer ones (found in upper layers). Thus, biologists have concluded that simpler forms of life existed first. These simpler forms of life were gradually added to or replaced by more complex forms.

Simple forms of life appear to have existed before complex forms.

From looking at the fossil record as a whole, the number of early forms of organisms was small. The number of forms increased more and more rapidly as time progressed. Earliest fossils represent aquatic organisms. Later fossils indicate that organisms began to live on land.

The fossil record is not perfect. Many fossils linking one organism to another have not been discovered. However, it seems to indicate that life forms on Earth have changed.

Fossil records indicate that life today is different from that of the past.

## 10:3 Comparative Anatomy

Study of the structures of different organisms is called **comparative anatomy.** Figure 10-6 shows the legs of several familiar animals. Note that the bones are similar but slightly different in structure. Each animal has a leg structure which is a variation of a common pattern.

Comparative anatomy is the study of structures of different types of organisms.

The legs of these animals are all used in walking, but the actual method of walking varies. The different bone structures

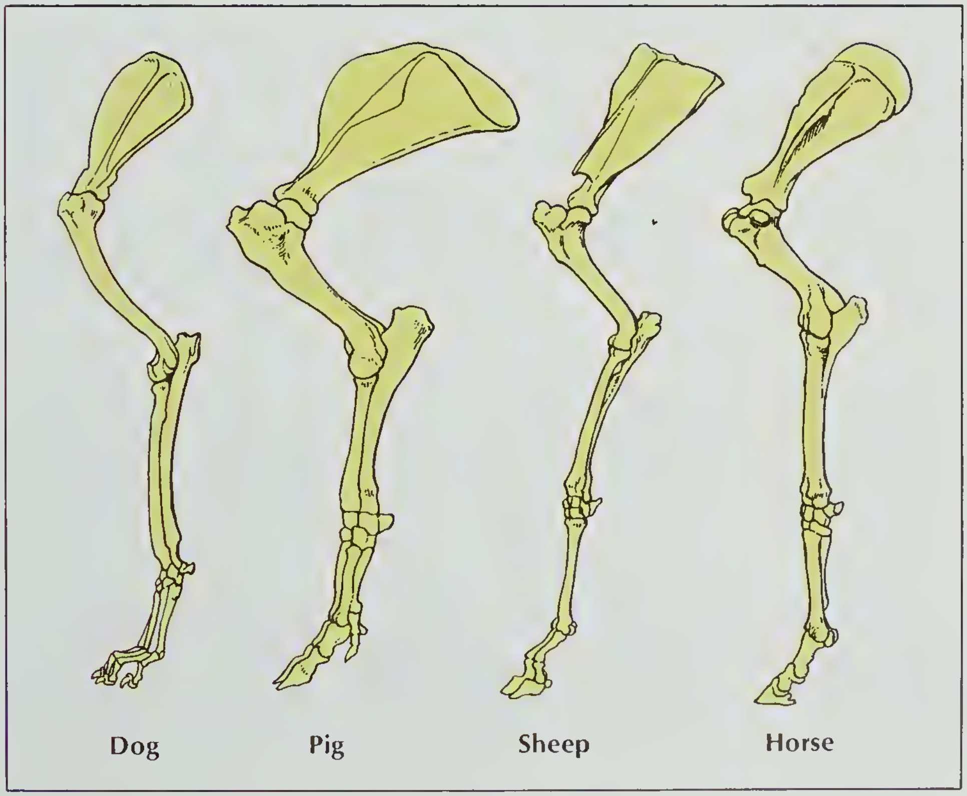


**FIGURE 10-6. The leg and foot structures of many vertebrates appear similar in the number and locations of the bones. Each, however, is slightly different.**

**HEALTH CARE.** The availability of health service is important to people who are sick or injured. These services depend on people employed in health occupations. Certain careers in some professional health fields—medicine, dentistry, pharmacy—require not only several years of preprofessional college training but also professional school education and a passing score on a state board examination. However, other careers in these fields require less specialized training.

Dentistry

- Dental assistant (JOB, VT)—prepares patients; helps dentist
- Dental hygienist (VT or BS)—cleans teeth, gives oral hygiene instruction
- Dental laboratory technician (JOB)—prepares dentures, inlays, and dental appliances
- Dentist (Doctor of Dental Surgery degree-6 yr.)—examines and treats people with tooth-related problems

Medical secretary (VT, SC)—office work for doctors, insurance companies, and others

Medical Practitioners

- Chiropractor (Doctor of Chiropractics degree-4 yr.)—treats human patients by manual manipulation of body parts; cannot prescribe medication
- Optometrist (Doctor of Optometry degree-6 yr.)—examines eyes for vision problems and disease
- Osteopathic physician (Doctor of Osteopathy degree-7 yr., IN)—diagnoses and treats human diseases, especially by manipulation of skeletal and muscular systems; can use all accepted methods of medical care
- Physician (Doctor of Medicine degree-7 yr., IN)—examines, diagnoses, and treats human disease and injury; often specialized
- Podiatrist (Doctor of Podiatric Medicine degree-6 yr.)—treats foot injury and disease
- Veterinarian (Doctor of Veterinary Medicine-6 yr)—diagnoses and treats animal disease and injury

Doug Martin

FIGURE C-2. Biology-related careers include the care of both animals and humans. (a) A veterinarian checks the leg of an injured dog. (b) A nurse carefully monitors the life functions of a prematurely born infant.

Nursing

- Licensed practical nurse, LPN (HS, 1 yr training)—provides nursing care to sick or injured patients
- Nursing assistant (JOB)—serves meals; provides for patient comfort; frees registered nurse and licensed practical nurse for more critical work
- Registered nurse, RN (Nursing school-2 to 5 yr.)—gives medication ordered by physician; observes patient symptoms and progress; supervises nursing assistants; teaches

Dietician (BS)—plans nutritious meals; supervises food service workers

Food technologist (BS)—investigates nature of food and applies this to processing, packaging, and storage of foods

Immunologist (MS)—studies how the body fights disease

Medical assistant (paramedic) (JOB, VT)—helps physician examine and treat patients; does clerical work

Medical lab worker: Assistant (JOB), Technician (College-2yr.), Technologist (College-4 yr.)—works in laboratory performing various medical tests; responsibility and test complexity depend on training and experience

Pharmacist (Pharmacy degree-5 yr., IN)—dispenses drugs and medicines prescribed by medical practitioners

Physical therapist (Physical therapy degree-4 yr.)—provides training and helps rehabilitate persons with muscle, bone, and nerve disease or injury

Physical therapy aide (JOB, JC)—assists physical therapist

## Additional Information

The following is a list of addresses for a few sources of additional information. Further information about biology-related careers and a more complete listing of additional sources can be found in the *Occupational Outlook Handbook* and *Keys to Careers in Science and Technology.* Check also with your school guidance counselors for any information they may be able to provide.

American Dental Association
Council on Dental Education
211 East Chicago Avenue
Chicago, IL 60611

American Institute of Biological Sciences
3900 Wisconsin Avenue, NW
Washington, DC 20016

American Medical Association
Council on Medical Education
535 North Dearborn Street
Chicago, IL 60610

ANA Committee on Nursing Careers
American Nurses' Association
2420 Pershing Road
Kansas City, MO 64108

*Keys to Careers in Science and Technology*
National Science Teachers Association
1742 Connecticut Avenue, NW
Washington, DC 20009

*Occupational Outlook Handbook*
U.S. Department of Labor
Bureau of Labor Statistics
Washington, DC 20212

*Opportunities in Biological Science Careers*
Vocational Guidance Manuals
Division of Data Courier, Inc.
Louisville, KY 40200

U.S. Civil Service Commission
Washington, DC 20415

U.S. Department of Agriculture
Forest Service
Washington, DC 20250

U.S. Department of Agriculture
Soil Conservation Service
Washington, DC 20250

# APPENDIX D

## Chemical Symbols and Formulas

### TABLE D-1. THE ELEMENTS AND THEIR SYMBOLS

| Element | Symbol | Element | Symbol | Element | Symbol | Element | Symbol |
|---|---|---|---|---|---|---|---|
| Actinium | Ac | Europium | Eu | Molybdenum | Mo | Scandium | Sc |
| Aluminum | Al | Fermium | Fm | Neodymium | Nd | Selenium | Se |
| Americium | Am | Fluorine | F | Neon | Ne | Silicon | Si |
| Antimony | Sb | Francium | Fr | Neptunium | Np | Silver | Ag |
| Argon | Ar | Gadolinium | Gd | Nickel | Ni | Sodium | Na |
| Arsenic | As | Gallium | Ga | Niobium | Nb | Strontium | Sr |
| Astatine | At | Germanium | Ge | Nitrogen | N | Sulfur | S |
| Barium | Ba | Gold | Au | Nobelium | No | Tantalum | Ta |
| Berkelium | Bk | Hafnium | Hf | Osmium | Os | Technetium | Tc |
| Beryllium | Be | Helium | He | Oxygen | O | Tellurium | Te |
| Bismuth | Bi | Holmium | Ho | Palladium | Pd | Terbium | Tb |
| Boron | B | Hydrogen | H | Phosphorus | P | Thallium | Tl |
| Bromine | Br | Indium | In | Platinum | Pt | Thorium | Th |
| Cadmium | Cd | Iodine | I | Plutonium | Pu | Thulium | Tm |
| Calcium | Ca | Iridium | Ir | Polonium | Po | Tin | Sn |
| Californium | Cf | Iron | Fe | Potassium | K | Titanium | Ti |
| Carbon | C | Krypton | Kr | Praseodymium | Pr | Tungsten | W |
| Cerium | Ce | Lanthanum | La | Promethium | Pm | Uranium | U |
| Cesium | Cs | Lawrencium | Lr | Protactinium | Pa | Vanadium | V |
| Chlorine | Cl | Lead | Pb | Radium | Ra | Xenon | Xe |
| Chromium | Cr | Lithium | Li | Radon | Rn | Ytterbium | Yb |
| Cobalt | Co | Lutetium | Lu | Rhenium | Re | Yttrium | Y |
| Copper | Cu | Magnesium | Mg | Rhodium | Rh | Zinc | Zn |
| Curium | Cm | Manganese | Mn | Rubidium | Rb | Zirconium | Zr |
| Dysprosium | Dy | Mendelevium | Md | Ruthenium | Ru | Element 104 | (Rf) |
| Einsteinium | Es | Mercury | Hg | Samarium | Sm | Element 105 | (Ha) |
| Erbium | Er | | | | | | |

### TABLE D-2. SOME COMMON COMPOUNDS

| Name | Formula | Name | Formula | Name | Formula |
|---|---|---|---|---|---|
| ammonia | $NH_3$ | fructose | $C_6H_{12}O_6$ | rust | $Fe_2O_3$ |
| calcium carbonate | $CaCO_3$ | glucose | $C_6H_{12}O_6$ | sodium hydroxide | $NaOH$ |
| carbon dioxide | $CO_2$ | glycerol | $C_3H_8O_3$ | sucrose | $C_{12}H_{22}O_{11}$ |
| chlorophyll-a | $C_{55}H_{72}O_5N_4Mg$ | glycine | $C_2H_5O_2N$ | table salt | $NaCl$ |
| ethyl alcohol | $C_2H_5OH$ | lactic acid | $CH_3CHOHCOOH$ | water | $H_2O$ |

# APPENDIX E

## SI Measurement

The SI system is a convenient, widely used system of measurement which has the advantage of units based on ten and multiples and fractions of ten. Table E-1 that follows is an extended version of Table 2-1. Information about converting from one SI unit to another follows the table.

**TABLE E-1. SI PREFIXES**

| Prefix | Symbol | Meaning | Multiplier (Numerical) | Multiplier (Exponential) |
|---|---|---|---|---|
| | | | **Greater than 1** | |
| tera | T | trillion | 1 000 000 000 000 | $10^{12}$ |
| giga | G | billion | 1 000 000 000 | $10^{9}$ |
| mega | M | million | 1 000 000 | $10^{6}$ |
| kilo | k | thousand | 1 000 | $10^{3}$ |
| hecto | h | hundred | 100 | $10^{2}$ |
| deka | da | ten | 10 | $10^{1}$ |
| | | | **Less than 1** | |
| deci | d | tenth | 0.1 | $10^{-1}$ |
| centi | c | hundredth | 0.01 | $10^{-2}$ |
| milli | m | thousandth | 0.001 | $10^{-3}$ |
| micro | μ | millionth | 0.000 001 | $10^{-6}$ |
| nano | n | billionth | 0.000 000 001 | $10^{-9}$ |
| pico | p | trillionth | 0.000 000 000 001 | $10^{-12}$ |
| femto | f | quadrillionth | 0.000 000 000 000 001 | $10^{-15}$ |
| atto | a | quintillionth | 0.000 000 000 000 000 001 | $10^{-18}$ |

The basic units for length, volume, and mass are the metre, litre, and kilogram respectively. The basic unit of time is the second. Larger and smaller units of measurement in SI are obtained by multiplying or dividing the base unit by some multiple of ten. Multiply to change from larger units to smaller units. Divide to change from smaller units to larger units. For example, to change 10 kg to g, multiply 10 kg × 1000 (for kilo-) = 10 000 g. To change 10 g to kg, divide 10 g ÷ 1000 (for kilo-) = 0.01 kg.

# GLOSSARY

**Pronunciation Key**

a . . . **back** (BAK)
er . . . **care, fair** (KER, FER)
ay . . . **day** (DAY)
ah . . . **father** (FAHTH ur)
ar . . . **car** (KAR)
ow . . . **flower, loud** (FLOW ur, LOWD)
e . . . **less** (LES)
ee . . . **leaf** (LEEF)
ih . . . **trip** (TRIHP)

i (i + con + e) . . . **idea, life** (i DEE uh, LIFE)
oh . . . **go** (GOH)
aw . . . **soft** (SAWFT)
or . . . **orbit** (OR but)
oy . . . **coin** (KOYN)
oo . . . **foot** (FOOT)
yoo . . . **pure** (PYOOR)
ew . . . **food** (FEWD)
yew . . . **few** (FYEW)
uh (u + con) . . . **comma, mother** (KAHM uh, MUTH ur)

sh . . . **shelf** (SHELF)
ch . . . **nature** (NAY chur)
g . . . **gift** (GIHFT)
j . . . **gem, edge** (JEM, EJ)
ing . . . **sing** (SING)
zh . . . **vision** (VIHZH un)
k . . . **cake** (KAYK)
s . . . **seed, cent** (SEED, SENT)
z . . . **zone, raise** (ZOHN, RAYZ)

**abdomen:** posterior body region of an arthropod; region in vertebrates housing many internal organs

**abiotic** (ay bi AHT ihk) **factors:** physical (nonliving) aspects which interact with the organisms of an ecosystem

**abscission** (ab SIHZH un): the falling of leaves from trees

**abscission layer:** group of cells which forms between the stem and the petiole of a leaf

**absorption spectra** (ub SORP shun • SPEC truh): spectra which have some wavelengths of light either reduced or absent

**abyssal** (uh BIHS ul) **zone:** deepest part of the ocean where light is absent

**acceleration center:** area in the medulla oblongata from which the accelerator nerves originate

**accelerator nerves:** nerves which increase the heartbeat by stimulating the S-A node

**acetylcholine** (uh seet ul KOH leen): neurotransmitter which is produced by the vagus nerves and inhibits the rate of contraction of heart muscle in humans

**acid:** substance which in solution has a greater concentration of hydrogen ions than hydroxide ions

**acid rain:** rain with a low pH

**acquired characteristic:** change in an organism caused by use or disuse of certain body parts

**actin** (AK tun): protein which makes up part of the filaments in striated muscle

**action potential:** reversal of polarity and flow of ions in a neuron caused by a stimulus

**activation energy:** energy necessary to start some chemical reactions

**active immunity** (ihm YEW nut ee): immunity or disease resistance resulting from production of antibodies by the host

**active site:** particular portion of an enzyme molecule which fits a substrate

**active transport:** energy-requiring process in which a membrane has an active role in the passage of materials across it

**adaptation:** inherited characteristic which promotes survival and reproduction in a natural environment

**adaptive advantage:** possessing a trait which makes a species better suited to its environment and makes its chances of reproducing better

**adaptive radiation:** the evolution of many new species from a common ancestor in a new environment

**adenine** (AD un een): one of the bases in nucleic acids

**adenosine diphosphate** (uh DEN uh seen • di FAHS fayt) **(ADP):** complex molecule containing adenine, ribose, and two phosphates

**adenosine triphosphate** (uh DEN uh seen • tri FAHS fayt) **(ATP):** complex molecule containing adenine, ribose, and three phosphates; used as an energy source in all organisms

**adhesion** (ad HEE zhun): attraction between unlike molecules

**adrenal** (uh DREEN ul) **cortex:** outer portion of the adrenal gland

**adrenal gland:** endocrine gland on top of each kidney

**adrenal medulla** (muh DUL uh): inner portion of the adrenal gland

**adrenaline** (uh DREN ul un): hormone secreted by the adrenal medulla; helps the body respond to emergencies; also called epinephrine

**adrenocorticotrophic hormone** (ACTH): hormone secreted by the anterior pituitary; stimulates the adrenal cortex to secrete its hormones

**adventitious** (ad ven TIHSH us) **roots:** roots which grow from the stems of plants allowing them to be vegetatively propagated

**aerobe:** organism which uses oxygen in respiration

**aerobic** (er ROH bihk) **respiration:** respiration which occurs in the presence of oxygen

**African sleeping sickness:** disease caused by a parasitic flagellate

**afterbirth:** part of the placenta that is expelled from the body after the birth of a baby

**agar:** substance made from brown algae used to make culture media gel

**agglutination:** process in which red blood cells clump together

**agglutinin** (uh GLEWT uh nun): antibody in blood that causes it to clump

**air sac:** respiratory structure in birds which fill with air as the lungs fill

**alcoholic fermentation:** type of anaerobic respiration used by plant cells and microbes

**aldosterone** (al DAWS tuh rohn): hormone secreted by the adrenal cortex; controls salt level in the blood

**algae:** unicellular or multicellular photosynthetic protists

**algal bloom:** rapid growth of algae

**alimentary** (al uh MEN tree) **canal:** long, hollow tube in animals through which food passes during digestion

**allantois** (uh LANT uh wus): sac which collects metabolic waste products in the shelled egg; also functions with the chorion in gas exchange

**allele** (uh LEEL): dominant or recessive form which a gene may take

**all or none response:** a muscle fiber contracts fully or does not contract at all; a neuron either carries an impulse or does not carry it at all

**alternation of generations:** life cycle in plants and plant-like protists, diploid and monoploid generations follow each other

**altitudinal** (al tuh TEWD nul) **succession:** continuous succession of community types from low to high altitudes

**alveoli** (al VEE uh li): small, moist sacs in the lungs; sites of gas exchange

**amino** (uh MEE noh) **acids:** compounds which are the building blocks of proteins

**amino group:** part of all amino acids which has the structural formula ($-NH_3$)

**ammonia** (**$NH_3$**): nitrogenous waste excreted by planaria

**ammonification** (uh moh nuh fuh KAY shun): stage of the nitrogen cycle during which bacteria metabolize amino acids and produce ammonia

**amniocentesis** (am nee oh sen TEE sus): technique in which some of the amniotic fluid surrounding an embryo is removed for analysis

**amnion** (AM nee ahn): fluid-filled sac surrounding the embryo; protects the embryo and keeps it moist

**amoebocyte** (uh MEE buh site): type of cell in sponges that moves in amoeboid fashion

**amoeboid** (uh MEE boyd) **motion:** movement by pseudopodia; motion of amoebae and amoebalike cells

**amphetamines:** stimulant drugs used for appetite control

**amphibians:** vertebrates which live both on land and in water; class Amphibia

**amplexus:** clasping of the female frog by the male that results in gametes being released at the same time

**ampulla:** bulb-shaped structure in the water-vascular system of starfish

**anaerobe:** organism which does not use oxygen in respiration

**anaerobic** (an uh ROH bihk) **respiration:** respiration in the absence of oxygen

**anal pore:** structure in ciliates which allows egestion of undigested materials

**anaphase** (AN uh fayz): phase of mitosis during which one strand of each chromosome is pulled to each pole of the cell; phase in meiosis I in which homologous chromosomes are separated and pulled to each pole of the cell

**anatomy:** study of the structures of organisms

**androgens** (AN druh junz): male sex hormones

**anemia** (uh NEE mee uh): disease in which the blood is low in red blood cells, hemoglobin, or total volume

**angiosperms** (AN jee uh spurmz): flowering plants

**animal:** multicellular, heterotrophic organism, usually mobile

**animal pole:** top half of a frog egg composed of cytoplasm and a dark pigment

**annelids:** segmented worms; phylum Annelida

**annual rings:** circular lines in a woody stem which represent growth during a year

**antennae:** sensory organs of arthropods

**anterior** (an TIHR ee ur): front part of an animal

**anterior pituitary:** one of the lobes of the pituitary gland; many of its hormones control other endocrine glands

**anther** (AN thur): male sporangium at the tip of stamens

**antheridium** (an thuh RIHD ee um): male sex organ in bryophytes and ferns

**anti-A agglutinin:** antibody contained in the plasma of blood type B

**anti-B agglutinin:** antibody contained in the plasma of blood type A

**antibiotic:** drug which cures certain bacterial diseases

**antibody** (ANT ih bohd ee): chemical formed in response to a virus or other foreign microorganism in the blood or tissues

**anticodon:** set of three bases at one end of tRNA; fits only with certain codon of mRNA

**antigen** (ANT ih jun): specific protein on the surfaces of red blood cells; any foreign protein which causes antibody formation

**antiserum:** solution of antibodies and blood serum used to fight disease

**anus** (AY nus): opening through which undigested materials are expelled

**aorta** (ay ORT uh): large artery leading from the heart

**aortic** (ay ORT ihk) **arches:** five pairs of enlarged tubes, "hearts," in annelids

**apical** (AY pih kul) **dominance:** retardation of growth of lateral buds in the presence of the apical bud

**apical meristem:** plant growth tissue located at the tip of roots and stems

**appendage** (uh PEN dihj): limb or other projection attached to the main trunk of an animal

**appendix:** small organ attached to the large intestine; vestigial in humans

**applied science:** using scientific knowledge to solve real problems

**aquatic** (uh KWAHT ihk): having to do with water

**arachnids** (uh RAK nudz): class of arthropods; spiders, ticks, mites, and scorpions

**arboreal:** tree dwelling

**archegonium** (ar kih GOH nee um): female sex organ in bryophytes and ferns

**archenteron** (ar KENT uh rahn): internal cavity in the developing embryo; develops into the alimentary canal

**artery:** blood vessel which carries blood away from the heart to the body

**arthropods:** animals having an exoskeleton and jointed appendages; phylum Arthropoda

**artificial selection:** procedure in which humans choose organisms to breed that have desirable features

**ascending colon:** portion of the large intestine into which undigested materials from the small intestine pass

**ascus:** saclike structure in which spores are produced by meiosis in certain fungi

**asexual** (ay SEK shul) **reproduction:** reproduction in which a single parent produces one or more offspring by mitosis

**association neuron:** neuron which connects sensory neurons and motor neurons in the brain and spinal cord

**asthma:** respiratory condition in which the muscles of the bronchial system contract, reducing the diameter of the air passages

**atherosclerosis** (ath uh roh skluh ROH sus): condition in which the arteries become lined with fatty deposits

**atom:** smallest particle of an element; basic building block of all matter

**ATP-ADP cycle:** series of reactions by which ATP is converted to ADP and ADP is converted back to ATP

**atrioventricular** (ay tree oh ven TRIHK yuh lur) **node (A-V node):** small bundle of tissue between atria and ventricles which receives the current from the S-A node

**atrium** (AY tree uhm): heart chamber which receives blood in vertebrates; also called auricle

***Australopithecus*** (aw stray loh PIHTH uh kus): genus of prehumans that lived around 2 million years ago in southern Africa

**autoclave** (AWT oh klayv): kind of equipment used in labs and hospitals to kill bacteria

**autonomic nervous system:** system which controls involuntary responses

**autosome** (AWT uh sohm): body chromosome, as distinguished from sex chromosome

**autotroph** (AWT uh trohf): organism which can produce its own food

**auxin** (AWK sun): plant hormone

**Aves:** class of vertebrates characterized by feathers and lightweight bones for flight

**axon** (AK sahn): long part of a neuron leading away from the cell body; transmits impulses away from the cell body

**bacilli** (buh SIHL i): rod shaped bacteria

**bacteria:** very small, prokaryotic, unicellular, heterotrophic organisms (lack nuclei and some organelles)

**bacterial transformation:** form of genetic recombination which occurs when one bacterium breaks open and part of its DNA enters another bacterium

**bacteriophage** (bak TIHR ee uh fayj): virus which reproduces in bacteria; also called phage

**balance:** scientific instrument used for measuring mass; process of making the number of atoms of each element agree on both sides of a chemical equation

**balanced equation:** chemical equation in which the number of atoms of each element agree on both sides

**ball and socket joint:** type of joint that can rotate as well as move side to side and back and forth

**barbiturates:** most powerful and most often abused depressants

**bark:** outermost layers of a woody stem

**basal body:** structure that attaches cilia and flagella to the inside of a cell

**base:** substance which in solution has a greater concentration of hydroxide ions than hydrogen ions; an alkaline solution; compound containing nitrogen which makes up part of a nucleic acid

**basic irritability:** cytoplasmic response to stimuli

**basidia** (buh SIHD ee uh): club-shaped, spore-producing structures in certain fungi

**B-cell:** lymphocyte which does not pass through the thymus gland; divides to form a clone and produces antibodies

**beech-maple forest:** climax community in northeastern United States

**behavior:** responses made by an organism to the stimuli of its environment

**behavioral** (bih HAY vyuh rul) **adaptation:** adaptation involving reactions to the environment

**benthos** (BEN thas): animals which live attached to or crawl on the ocean floor

**beriberi:** deficiency disease caused by lack of vitamin $B_1$

**beta cell:** type of islet of Langerhans cell that produces insulin

**bicuspid** (bi KUS pud) **valve:** valve which prevents blood from being forced back into the left atrium when the left ventricle contracts

**bilateral** (bi LAT uh rul) **symmetry:** body pattern in which only one longitudinal cut will produce two sides that are mirror images

**bile:** greenish liquid produced by the liver and stored in the gall bladder; emulsifies fat in the small intestine

**bile salts:** substances contained in the gall bladder that break up fat globules in the intestine

**binomial nomenclature** (bi NOH mee ul • NOH mun klay chur): two-term naming system used in classifying organisms

**biogenesis** (bi oh JEN uh sus): theory which states that at the present time and under present conditions on earth, all living things are produced from other living things

**biological clock:** mechanism which controls certain time-related activities of animals

**biological control:** using natural, biological methods of controlling pest populations

**biological magnification:** increased concentration of chemicals along a food chain

**biologist:** one who studies biology

**biology:** study of life

**biomass** (BI oh mas): total mass of a group of organisms per unit of area

**biome** (BI ohm): communities characterized by the same major life forms, such as tundra

**biosphere** (BY uh sfir): total world of life

**biotic** (bi AHT ihk) **factors:** relationships among living organisms in an ecosystem

**biotic potential:** tendency of all organisms to reproduce in large numbers; reproductive potential

**bipedal** (bi PED ul) **locomotion:** locomotion on two feet

**birth:** expulsion of the baby from the uterus

**birthrate:** number of organisms born in a given time period

**bivalves** (BI valvz): mollusks which have two shells; includes clams, oysters, and mussels

**blade:** expanded part of a leaf

**blastocoel** (BLAS tuh seel): fluid-filled cavity inside the blastula

**blastocyst:** ball of cells formed as a zygote begins to divide

**blastopore** (BLAS tuh por): opening formed by the dorsal lip cutting into the blastula

**blastula** (BLAS chuh luh): hollow ball of cells in the early development of an embryo

**blood:** liquid which serves as an exchange medium between the internal parts of an organism and its external environment

**blood clot:** network of fibers and other blood parts which covers a wound and prevents the loss of excess blood

**blood pressure:** pressure exerted by the blood on the walls of the blood vessels

**body stalk:** structure which connects the trophoblast and the embryo to the uterine wall

**bone:** living tissue which makes up the endoskeleton of most vertebrates

**bone marrow:** tissue in the hollow part of bones

**bony layer:** layer of bone which contains minerals

**botulism** (BACH uh lihz um): a sometimes fatal disease resulting from bacterial wastes in improperly canned food

**Bowman's capsule:** cup-shaped part of a nephron

**brain:** major coordinating center in vertebrates; nerve center in invertebrates similar in position and function to the vertebrate brain

**breathing:** movement of air into and out of the lungs of complex animals

**breathing center:** area in the medulla oblongata which controls the breathing rate

**bromeliad:** epiphyte that lives in the canopy of the tropical rain forest

**bronchi** (BRAHN ki): two large tubes branching from the trachea in the lungs

**bronchial tubes:** small branches of the bronchi

**bronchioles** (BRAHN kee ohlz): tiny branches of the bronchial tubes

**bryophytes** (BRI uh fites): most primitive of true land plants; mosses and liverworts

**bud:** protected, dormant meristem which may develop into new stems, flowers, or leaves

**bud scale:** modified leaf which protects a bud

**bud scale scar:** place where bud scales surrounded a bud

**budding:** type of vegetative propagation in which an outgrowth forms on the parent organism and later separates giving rise to a new organism

**bulb:** short underground stem surrounded by many scales (modified leaves)

**Calvin cycle:** cyclic pattern of reactions in the dark reaction of photosynthesis

**cambium:** tissue which produces additional xylem and phloem cells as a plant grows in diameter

**camouflage** (KAM uh flahj): any means of blending with the environment

**cancer:** disease characterized by lack of control of cell division

**canopy:** top layer of a forest where most of the food is produced

**cap:** top, umbrellalike portion of a mushroom; guanine at the end of mRNA

**capillaries:** smallest branches of blood vessels where materials of the blood and cells are exchanged; connect arteries and veins

**carbohydrates:** organic compounds composed of carbon, hydrogen, and oxygen; used for energy sources in organisms

**Carbon-14:** a radioactive isotope with a half-life of 5730 years

**carbon compound:** chemical compound containing carbon

**carboxyl** (kar BAHK sul) **group:** part common to all fatty acids that has a structural formula of (-COOH)

**carboxyhemoglobin:** molecule formed when carbon dioxide combines with hemoglobin in blood

**cardiac** (KARD ee ak) **muscle:** muscle of which the heart is composed

**carnivore** (KAR nuh vor): consumer which feeds on other consumers; meat eater

**carotenes** (KER uh teenz): yellow or orange pigments present in most autotrophs

**carrier molecule:** protein that combines with certain particles and helps them pass across the cell membrane

**carrying capacity:** number of individuals of a population which a particular environment can support

**cartilage** (KART ul ihj): tough, flexible, connective tissue which does not contain minerals

**cell:** smallest living unit of which all organisms are composed

**cell body:** portion of a neuron most resembling other cells; contains a nucleus and cytoplasm

**cell fractionation:** separation of cell parts

**cell membrane:** structure that separates the components of a cell from its environment

**cell plate:** structure completed in plants to separate the daughter cells formed in mitosis

**cell theory:** concept which applies to all living things; the cell is the basic unit of structure and function and all cells are produced from other cells

**cell wall:** structure which surrounds the plasma membrane of plant cells; composed of cellulose or other carbohydrates

**cellular respiration:** process by which the energy of glucose is converted to the energy of ATP in a cell

**cellulose:** polysaccharide of plants

**Celsius** (SEL see us): scale for measuring temperature which has 0° as the freezing point and 100° as the boiling point of water

**cenozoic:** era of the geologic timetable which lasted from 75 000 000 years ago to the present

**centimetre:** measurement of length in the SI system equal to 1/100 of a metre

**centipede:** member of class of arthropods characterized by one pair of legs per segment; class Chilopoda

**central disc:** center part of a starfish from which arms stick out

**central nervous system:** control center for the entire nervous system

**centrifuge:** instrument that spins materials at high speed

**centrioles** (SEN tree olz): pair of organelles which play an important role in division of animal cells

**centromere** (SEN truh mihr): round body made of chromatin which holds the two strands of a chromosome together

**cephalothorax** (sef uh luh THOR aks): one of the two body sections of crustaceans; the result of fusion of the head and thorax

**cerebellum** (ser uh BEL um): convoluted region of the hindbrain lying at the back of the head below the cerebrum

**cerebral cortex:** convoluted surface of the cerebrum

**cerebrospinal fluid:** fluid in brain and spinal cord; protects brain from shock

**cerebrum** (suh REE brum): forebrain of humans

**cervix** (SUR vihks): small opening between the vagina and uterus

**chelicerae** (kih LIHS uh ree): fanglike or pincerlike mouthparts in arachnids

**chemical bond:** force which holds atoms together

**chemical change:** process by which atoms or molecules are rearranged; also called chemical reaction

**chemical energy:** energy within molecules

**chemical equation:** statement using formulas to describe a chemical reaction

**chemical formula:** combinations of symbols which represent the number and kind of each atom in a compound

**chemical property:** property of a substance which depends on how the substance reacts with other substances

**chemical reaction:** chemical change; rearranging of the atoms or molecules of substances to form completely new substances with new properties

**chemical symbol:** shorthand method of representing an element

**chemosynthesis** (kee moh SIHN thus sus): process in which inorganic materials such as iron, sulpher, and nitrogen compounds are used to make carbohydrates

**chemotherapy:** use of chemicals to treat disease

**chiliped** (KEE luh ped): legs modified as claws found on some crustaceans used for trapping food and for defense

**chitin** (KITE un): carbohydrate material forming the walls of most fungi; carbohydrate material forming one of the main components of an arthropod's exoskeleton

**chlorophyll:** green pigment which is essential for the conversion of light energy to chemical energy in autotrophic organisms

**chloroplast** (KLOR uh plast): cellular organelle in autotrophs which contains chlorophyll

**cholinesterase** (koh luh NES tuh rays): enzyme that breaks down acetylcholine into two smaller molecules

**chordates** (KOR dates): members of phylum Chordata, includes vertebrates

**chorion** (KOR ee ahn): thin membrane inside the shell of a land egg which functions in gas exchange; a membrane in mammals contributing to the formation of the placenta

**chromatid** (KROH muh tid): individual strand in a double-stranded chromosome

**chromatin** (KROH mut un): mass of material inside the nuclear membrane which appears as chromosomes during cell division

**chromatophore** (kroh MAT uh for): cell containing one or more pigments

**chromosome** (KROH muh sohm): distinct body in the nucleus which appears during cell division; contains genes

**chromosome theory of heredity:** genes are located on chromosomes

**chunk feeder:** animal which eats pieces of food material

**chyme** (KYM): liquid acid form of food after digestion in the stomach

**cilia** (SIHL ee uh): tiny, hairlike projections; used for locomotion in some one-celled organisms; also present on some cells of multicellular organisms

**ciliary** (SIHL ee er ee) **motion:** locomotion achieved by movement of cilia

**ciliates** (SIHL ee ayts): protozoa which have cilia

**circulatory** (SUR kyuh luh tor ee) **system:** system made up of the blood and the structures through which it passes

**cirri:** large bundles of cilia found in some protists

**class:** division of classification system which represents a subdivision of a phylum

**cleavage** (KLEE vihj): series of many cell divisions in the developing embryo

**climax community:** final stage in the evolution of a community

**cloaca** (kloh AY kuh): a common chamber that receives the digestive and excretory wastes as well as products of the reproductive system

**clone:** strain of genetically identical cells

**closed circulatory system:** system in which blood is always in the blood vessels

**cocci** (KAHK si): round- or sphere-shaped bacteria

**cochlea:** fluid-filled canal in the inner ear

**codon** (KOH dohn): sequence of three bases representing a certain amino acid

**coelenterates:** simple animals characterized by tentacles with stinging cells, two cell layers, and a single body opening; phylum Coelenterata

**coelom** (SEE lum): body cavity which houses the major organs in annelids and more complex animals

**coenzyme:** molecules with which enzymes temporarily join during a reaction

**cohesion** (koh HEE zhun): clinging together of the same kind of molecules

**coleoptile** (koh lee AHP tul): leafy tip of a seedling

**collar cells:** flagellated endoderm cells which line the body cavity of sponges; function in trapping food

**colon** (KOH lun): large intestine

**colorblindness:** generic, sex-linked trait that makes a human unable to distinguish red or green

**commensalism** (kuh MEN suh lihz um): relationship in which one organism (commensal) benefits from another organism (host) without affecting it

**common bile duct:** canal formed by the merging of the bile duct and the pancreatic duct; empties into the duodenum

**communication:** use of symbols to represent ideas

**community:** naturally occurring group of organisms living in a certain area

**companion cells:** cells with nuclei that lie next to seive tubes in a stem

**comparative anatomy:** studies of similar structures among organisms

**comparative biochemistry:** studies of chemical similarities among organisms

**comparative embryology:** studies of similar development among different organisms

**competitive exclusion principle:** two populations cannot occupy the same ecological niche

**complement:** set of enzymes in the bloodstream which attacks foreign cells

**complete metamorphosis:** four-stage process of development in insects

**compound:** substance composed of different kinds of atoms

**compound leaf:** leaf blade subdivided into leaflets

**concept:** idea

**concussion:** brain injury which may result from a severe fall or blow to the head

**conditioned response:** involuntary response to a stimulus that does not normally cause the response; voluntary response to get a desired effect; depends on type of conditioning

**conditioning:** type of learning in animals

**conductor:** structure that transmits nerve impulses

**conidium** (kuh NIHD ee um): spore formed by mitosis at the tip of a conidiophore

**conidiophore** (kuh NIHD ee uh for): hyphae found in some molds on which conidia are produced

**cone:** seed-bearing or pollen-bearing structure of gymnosperms

**conifers** (KAHN uh furs): pines and their relatives; cone-bearing gymnosperms

**conjugation:** fusion of nuclear material of two cells

**consumer:** living things which obtains food from other organisms

**continuous variation:** existence of varying degrees of a characteristic; controlled by more than one pair of genes

**contour plowing:** conservation practice in which land is plowed along its natural contours, reducing erosion from water runoff

**contractile** (kun TRAK tul) **vacuole:** organelle which pumps excess water from a protozoan

**control group:** group which is identical to the experimental group except for the variable being tested

**controlled experiment:** experiment in which all factors are identical except the one being tested

**convergence** (kun VUR junts): evolutionary process in which distantly related species produce descendants which resemble each other

**convolutions** (kahn vuh LEW shunz): folds in the cerebral cortex

**cork:** cells which make up the outer bark of trees and woody shrubs

**corpus luteum** (KOR pus • LEWT ee um): yellow tissue that forms from the ruptured follicle

**corpus luteum stage:** stage in the menstrual cycle during which the corpus luteum produces progesterone to maintain the uterus for pregnancy.

**cortex:** food storage area in roots and stems; outer part of kidney; outer part of adrenal gland; outer part of cerebrum

**cortisol:** hormone which causes fats and proteins to be converted to glucose; secreted by the adrenal cortex

**cortisone:** hormone secreted by the adrenal cortex, often administered in synthetic form to counteract pain and swelling

**cotyledon** (kaht ul EED un): seed leaf, stores food for the embryo

**courtship patterns:** signals used by animals to identify members of their own species ready for mating

**courtship behavior:** complex behavior of animals

**covalent** (koh VAY lunt) **bonds:** sharing of electrons between atoms

**cranial nerves:** nerves from the brain which carry impulses of the sensory-somatic system

**creatine phosphate (CP):** compound that can quickly be converted to ATP for energy for muscle movement

**cretin:** malformed, mentally retarded dwarf suffering from cretinism

**cretinism** (KREET uhn ihz um): disease caused by a great deficiency of thyroxine in early childhood; victim is called a cretin

**cristae** (KRIS tee): folds on the inner layer of mitochondria

**Cro-Magnon:** type of modern human that lived 20 000 to 50 000 years ago

**crop:** food storage organ in the alimentary canal of an earthworm

**crop rotation:** conservation practice in which different crops are planted in a field from year to year

**cross-over:** an exchange of segments of chromosomes between two homologous chromatids

**crossing-over:** exchange of segments of chromosomal material between two strands of a tetrad; occurs during prophase of meiosis I

**cross-pollination:** pollination between flowers of separate plants

**crustaceans** (krus TAY shee uns): class of arthropods which includes lobsters, crayfish, shrimp, and crabs

**cryptic coloration:** type of camouflage in which the color of an organism blends with the environment

**cultural control:** the breeding, planting, and harvesting of crops by methods which reduce pest damage

**cultural evolution:** changes in culture which have reduced natural selection for humans

**culture:** knowledge, customs, and laws into which each person is born

**curare:** muscle relaxant that combines with receptors for acetylcholine on muscle cells

**cutin:** waxy material covering the epidermis of a leaf that helps prevent water loss

**cyclic AMP:** "second messenger" formed by adrenaline

**cytochrome** (SITE uh krohmz): chemicals contained in mitochondria that function in aerobic respiration

**cytoplasm** (SITE uh plaz um): protoplasm outside the nucleus of the cell

**cytosine** (SITE uh seen): one of the bases in the nucleic acids

**dark reaction:** phase of photosynthesis in which the actual synthesis of glucose occurs

**Darwinism:** theory of evolution first proposed by Charles Darwin stating that the organisms best adapted to an environment are the ones that survive and reproduce

**data:** scientific facts

**daughter cells:** two cells formed as the result of mitosis of a single cell

**day-neutral plant:** plant whose flowering does not depend on the length of daylight or darkness

**DDT:** pesticide which kills insects by attacking the nervous system; nonbiodegradable, passed along food chains

**death rate:** number of organisms that die in a given period of time

**deciduous** (dih SIHJ uh wus) **forest:** forest in which leaves are periodically shed from the trees

**decomposer:** organism such as bacteria or fungi which causes decay

**degenerative** (dih JEN uh ruh tihv) **evolution:** process in which organisms lose some of their features as they evolve from a more complex form into a simpler one

**dehydration synthesis:** chemical reaction in which a large molecule is formed from smaller molecules by removing water

**dehydrogenase:** an enzyme that removes hydrogen

**dendrite** (DEN drite): highly branched structure at one end of a neuron

**denitrification** (dee ni truh fuh KAY shun): process by which nitrogen is released from the soil by the action of denitrifying bacteria

**density:** the amount of matter that something contains in a certain volume

**deoxyribonucleic** (dee AHK sih ri boh noo klay ihk) **acid** (**DNA**): nucleic acid that contains the "genetic message"

**deoxyribose:** a sugar which joins with a nitrogen base and a phosphate group to form a nucleotide

**depressant:** one of a major group of drugs which reduce the reactions of the central nervous system

**descending colon:** section of the large intestine which leads to the rectum

**desert:** biome of arid regions where rainfall is less than 25 cm per year; sparse, widely-spaced vegetation

**desmids:** form of green algae

**development:** series of changes a living thing undergoes in attaining its final form

**diabetes insipidus** (ihn SIHP ud us): disease caused by secretion of too little vasopressin, characterized by frequent urination and constant thirst

**diabetes mellitus** (MEL ut us): disease in which a sufficient quantity of the hormone insulin is not produced; characterized by frequent urination and constant thirst as a result of a high blood sugar level, also called sugar diabetes

**diaphragm:** large, muscular sheet which separates the chest from the abdomen, important in breathing

**diastole** (di AS tuh lee): short period of "rest" after the heart contracts

**diatomaceous earth:** huge deposit of cell walls of dead diatoms

**diatoms** (DI uh tahmz): unicellular golden algae

**dicot** (DI kaht): plants whose seeds contain two cotyledons

**differentiation** (dihf uh ren chee AY shun): series of changes which result in the formation of specialized body cells and parts

**diffusion** (dihf YEW zhun): random movement of particles resulting in their movement from a region of greater concentration to one of lesser concentration

**digestion:** process of breaking large molecules into smaller ones by chemical and physical means

**dinoflagellates:** unicellular algae with two flagella for locomotion

**dipeptide:** two amino acids joined together by a peptide bond

**diploid** (DIHP loyd) **number:** a chromosome number equal to twice that found in the gametes

**disaccharide:** double sugar formed by the combination of two monosaccharides

**dissociation:** process in which the ions of ionic compounds separate in solution

**divergence** (di VUR junts): evolution of a species into two or more species with different characteristics

**division of labor:** organization of parts or organisms for specific jobs

**dominant** (DAHM un nunt) **species:** characteristic species of a community

**dominant trait:** genetic trait which dominates or prevents the expression of the recessive trait

**dormancy** (DOR mun see): period of inactivity of a seed or spore before germination; period of little or no activity in some types of animals

**dorsal** (DOR sul): toward the back

**dorsal aorta:** aorta that carries blood from the gills to all parts of a fish

**dorsal blood vessel:** major blood vessel on the back side of an annelid worm

**dorsal lip:** edge of blastopore dorsal to the embryo

**Down's syndrome:** abnormality caused by nondisjunction, characterized by eye shape that looks like that of people of the Mongoloid race, mental retardation, short arms and legs, and internal malformations; Mongolism

**drone:** male bee which developed from an unfertilized egg

**duet rule:** atoms with only one energy level acquire two electrons in forming molecules

**duodenum** (dew uh DEE num): portion of the small intestine closest to the stomach

**dynamic equilibrium** (di NAM ihk • ee kwul LIHB rec um): state in which the number of particles entering and leaving a cell is equal

**ecdyson** (EK duh sahn): hormone which causes molting

**echinoderms:** marine animals characterized by spiny skin and radial symmetry; phylum Echinodermata

**ecological niche:** the specific role an organism plays in a community

**ecological succession** (ee kuh LAHJ ih kul • suk SESH un): series of changes in a community during its evolution

**ecology:** study of the relationships between organisms and their environment

**ecosystem** (EE koh sihs tum): interaction of a community with its physical environment; an ecological system

**ectoderm** (EK tuh durm): outer layer of cells in an embryo or mature animal

**ectotherm** (EK tuh thurm): cold-blooded animal; animal whose body temperature is not internally regulated but rather approximates that of the environment

**effector** (ih FEK tur): organ which carries out the appropriate response to a stimulus

**egestion:** the elimination of undigested food

**egg:** female reproductive cell, also called an ovum

**electron:** negatively-charged particle of an atom

**electron cloud:** description of probable electron location around the nucleus of an atom

**electron microscope:** microscope which uses a beam of electrons instead of light

**element:** substance composed of only one type of atom

**elephantiasis:** a disease caused by *Filaria* roundworms

**elongation region:** cells of the meristem which grow only in length adding to the length of a young stem or root

**embryo:** developing plant or animal after fertilization

**embryology** (em bree AHL uh jee): study of development

**embryonic induction** (em bree AHN ihk • ihn DUK shun): hypothesis that a particular section of an embryo influences, or induces, the development of an adjacent region

**emigration:** movement of animals out of an area

**emphysema:** respiratory disease linked to smoking in which the bronchioles become inflamed

**end brush:** filaments forming the end of an axon

**endergonic** (en dur GAHN ihk) **reaction:** chemical reaction which requires energy

**endocrine** (EN duh krun) **gland:** ductless gland, pours hormones directly into blood

**endocrinology** (en duh krih NAHL uh jee): study of endocrine glands and hormonal control

**endocytosis** (en duh si TOH sus): process in which a cell uses energy to surround and take in large substances

**endoderm** (EN duh durm): inner layer of cells in an embryo or mature animal

**endoplasmic reticulum** (en duh PLAZ mihk • rih TIHK yuh lum): network of tubelike structures in most cells; may be a transport system for cellular materials

**endoscope:** device which allows a fetus to be viewed while it is still in the mother

**endoskeleton** (en doh SKEL ut un): internal skeleton

**endosperm** (EN duh spurm): mass of tissue in a seed, the food source for the germinating plant

**endosperm nucleus:** $3n$ structure formed when the sperm nucleus joins with the polar nuclei in a flower

**endospore:** type of spore formed from a bacterial cell during unfavorable conditions

**endotherm** (EN duh thurm): warm-blooded animal, a fairly constant body temperature regulated internally

**endotoxin:** poisonous chemical released when bacteria die and break open

**energy:** ability to do work and cause changes

**energy level:** distance at which an electron travels around the nucleus of an atom

**enkephalin:** neuropeptide that reduces pain

**environment:** all factors that act upon an organism

**environmental resistance:** total of the environmental factors which check the biotic potential of a population

**enzyme** (EN zime): protein which activates a chemical reaction in a cell

**enzyme induction:** process in which a substance entering a cell causes the cell to start producing a certain enzyme

**epicotyl** (EP ih kaht ul): embryonic seed structure, first true leaves of the plant

**epidermis** (ep uh DUR mus): outermost layer of cells of an organism

**epiglottis** (ep uh GLAHT us): structure which covers the opening to the trachea when a person swallows food

**epinephrin:** main hormone of the adrenal medulla which prepares the body to cope with stress

**epiphyte** (EP uh fite): plant which lives as a commensal in the canopy of trees

**era:** division of time used by geologists to divide the earth's history

**erosion** (ih ROH zhun): naturally-occurring process in which topsoil is removed by the action of water and wind

**erythrocyte** (ih RIHTH ruh site): red blood cell, produced in bone marrow; important in transport of oxygen and carbon dioxide

**esophagus** (ih SAHF uh gus): tube which passes food from the mouth or throat to other digestive organs in a variety of animals

**essential nutrient:** material needed by cells for life

**estivation** (es tuh VAY shun): period of inactivity and low metabolism similar to hibernation but occurring in hot weather

**estrogen** (ES truh jun): female sex hormone

**estrous** (ES trus) **cycle:** entire series of chemical and physical changes leading up to the production of mature eggs

**eukaryote** (yew KER ee oht): organism with cells that have true nuclei

**Eustachian tube:** a canal which connects the middle ear to the nasal passages and throat

**eutrophication:** aging and death of a lake, the result of upsetting the ecological balance

**evolution:** process of change with time during successive generations among living things

**excretion:** release and removal of harmful metabolic by-products

**excretory canal:** structure in a planarian which collects excess water from tissues

**excretory duct:** branch of excretory canal which opens as a pore on the surface of a planarian; excess water leaves through the pore

**excurrent pore:** opening in a sponge through which water leaves

**exergonic** (ek sur GAHN ihk) **reaction:** chemical reaction which releases energy

**exocytosis** (ek soh si TOH sus): process in which materials are expelled from a cell through the action of membranes fusing

**exon:** sections of DNA that contain the information that codes for the protein product of the gene

**exoskeleton** (ek soh SKEL ut un): external skeleton

**exotoxin:** poisonous chemical released by living bacteria

**experimental group:** part of an experiment in which the variable factor is tested

**experimentation:** scientific testing of a hypothesis

**expiration:** process in which air is expelled from the lungs

**extensor** (ihk STEN sur): muscle which, when contracted, causes a joint to straighten

**external fertilization:** fertilization in animals in which the egg is fertilized outside the female's body

**external respiration:** exchange of gases between the circulating fluid and the external environment

**extinct:** no longer existing form of life

**extracellular** (ek struh SEL yuh lur) **digestion:** digestion which occurs outside cells

**extract:** solution of a chemical obtained from cells

**eyespots:** two light-sensitive organs at the anterior end of planarians

**facillitated diffusion:** process in which carrier molecules help other molecules to move across cell membranes

**fact:** observed phenomenon agreed upon by a number of people; something about which there is no doubt

**FAD:** flavin adenine dinucleotide; a coenzyme that transports hydrogens and thus electrons in respiration

**Fallopian** (fuh LOH pee un) **tube:** another name for oviduct

**family:** subdivision of an order in the complete classification of an organism

**fatty acid:** complex molecule containing a carboxyl group; part of a fat molecule

**feces** (FEE seez): solid waste material, egested through the anus

**feedback mechanism:** system in which control over the glands depends on information received from them

**feeding level:** level of energy transfer in an ecosystem

**fermentation:** anaerobic respiration

**ferns:** vascular plants that have roots, stems, leaves, and rhizomes and reproduce by spores

**fertility factor:** genetic information located on plasmid in certain bacteria that are designated $F^+$ (Other bacteria without this factor are $F^-$.)

**fertilization:** fusion of sperm and egg

**fetoscopy** (fee TAHS kuh pee): medical test which allows direct observation of the fetus and surrounding tissues

**fetus** (FEET us): an embryo that is at least eight weeks old

**fiber:** a skeletal muscle cell

**fibril:** unit which makes up fibers of striated muscle

**fibrin** (FI brun): long strands of protein which form a blood clot

**fibrous** (FI brus) **root system:** system of many secondary roots and root hairs

**filament:** stalklike portion of a stamen; unit which makes up fibrils in striated muscle

**filter feeder:** animal which takes food from water as it flows through the animal

**first filial** (FIHL ee ul) **generation:** first offspring produced from a parental cross

**first-order consumer:** consumer which feeds directly on a producer; herbivore

**first polar body:** one of the two cells produced from the primary oocyte during meiosis I; very small cell

**fission** (FIHSH un): asexual reproduction in which one organism divides into two small organisms of equal size

**flagella** (fluh JEL uh): long, whiplike projections of a cell used for locomotion

**flagellar motion:** locomotion achieved by movement of flagella

**flagellate:** protozoan which moves by means of flagella

**flame cell:** cell with flagella which moves water into and along the excretory canal in a planarian

**flatworms:** bilaterally symmetrical, aquatic, semiaquatic, or parasitic organisms; members of phylum Platyhelminthes

**flexor** (FLEK sor): muscle which causes the bending of a joint

**florigen:** hormone that promotes flowering

**flourescence:** energy given off as light

**flower:** reproductive organ in angiosperms

**flower scar:** place on the stem where a flower was once attached

**follicle** (FAHL ih kul): cell nest within an ovary; site of egg development

**follicle stage:** stage in the menstrual cycle during which an egg matures and the preparation of the uterus for a possible pregnancy begins

**follicle-stimulating hormone (FSH):** hormone which stimulates the ripening of eggs within the follicle of the ovary; hormone that stimulates sperm production in males

**food:** substance which provides energy required by living systems

**food chain:** passage of energy and materials through a community

**food vacuole:** structure within some protozoa that collects and digests food

**food web:** all the possible feeding relationships in an ecosystem

**foot:** muscular organ in mollusks used for locomotion

**forebrain:** one of the three general areas of the vertebrate brain

**forest floor:** bottom-most strata of a forest

**fossil:** any evidence or part of a once-living thing

**fossil fuels:** fuels made from the remains of once-living organisms

**fragmentation:** form of vegetation propagation in which a part of an organism breaks off and grows

**fraternal** (fruh TURN ul) **twins:** twins which develop when two different eggs are fertilized

**frond** (FRAHND): fern leaf, highly branched, often with a lacy appearance

**fruit:** enlarged ovary of a plant that aids in seed dispersal

**fruit scar:** place on a stem where a fruit was once attached

**fungi:** plantlike, heterotrophic protists; members of phylum Mycophyta

**fungi:** heterotrophic, plantlike organisms which reproduce by forming spores and by other means

**fusion:** uniting of two sets of DNA; sexual reproduction

**galactose:** a simple sugar found in milk

**galactosemia:** a genetic disease in which galactose cannot be converted to glucose and instead builds up and causes nerve damage

**gall bladder:** organ beneath the liver in which bile is stored

**Galapagos** (guh LAHP uh gus) **Islands:** islands located about 1000 km west of South America at the equator

**gametes** (GAM eets): sex cells; sperms and eggs

**gametophyte** (guh MEET uh fite) **generation:** the monoploid part of the life cycle of a plant or plantlike protist

**ganglia** (GANG glee uh): knotlike bundle of nerve tissue

**gas exchange:** movement of oxygen and carbon dioxide between organisms and their environment

**gasohol** (GAS uh hahl): alcohol mixed with gasoline and used for fuel

**gastric glands:** glands in the stomach that secrete gastric juice

**gastric juice:** fluid secreted into the stomach by gastric glands that contains enzymes necessary for digestion

**gastrin** (GAS trun): hormone which stimulates the secretion of gastric juice

**gastrovascular** (gas troh VAS kyuh lur) **cavity:** internal area of coelenterates

**gastrula:** stage of the developing embryo following the blastula stage

**gastrulation** (gas truh LAY shun): movement of cells from the outside surface of the blastula through the blastopore into the interior of the blastula; process in which cell layers are formed

**Geiger counter:** instrument that detects radioactive particles being given off

**gel:** somewhat solidified state such as is characteristic of the cytoplasm at times

**gemmule** (JEM yewlz): reproductive cell of a sponge enclosed by a tough, outer covering that is highly resistant to dryness and cold

**gene:** unit responsible for transmitting hereditary traits; segment of a DNA molecule

**gene linkage:** presence of genes for different traits on the same chromosome

**gene pool:** all the genes of a population; sum of genetic information which will be passed to each new generation

**generative nucleus:** nucleus of a pollen grain, produces two monoploid sperm nuclei

**genetic continuity:** reproduction of offspring having the same set of features as the parent

**genetic counseling:** type of counseling in which parents can be advised of their chances of having offspring with a hereditary disease

**genetic engineering:** altering an organism's genetic makeup

**genetic map:** diagram indicating locations of genes on a chromosome

**genetic recombination:** rearranging of genetic instructions

**genetics** (juh NET ihks): science of heredity

**genotype** (JEE nuh tipe): particular combination of alleles of an organism

**genus** (JEE nus): classification division between family and species; first name in the scientific name of an organism

**geographic isolation:** division or separation of populations by geographical features

**geothermal energy:** energy created by the natural heat of the earth

**geotropism** (jee oh TROH pihz um): plant growth response to gravity

**germ theory of disease:** theory proposed by Louis Pasteur that stated that bacteria can cause disease

**germinate** (JUR muh nayt): begin development

**gestation** (jeh STAY shun) **period:** length of pregnancy

**gibberellin** (jihb uh REL un): chemical regulator affecting plant growth

**gill:** respiratory organ in fish and other aquatic animals; spokelike structure in the cap of a mushroom where spores are produced

**gill chamber:** area in which gills are located in fish

**gill filaments:** double rows of thin-walled tissue in gills through which capillaries pass

**gizzard:** digestive organ in which food is ground up in earthworms and birds

**gliding joint:** joint in which bones move easily over one another in a back and forth motion

**glomerulus** (gluh MER uh lus): mass of capillaries in the center of each Bowman's capsule of a kidney

**glucose:** simple sugar produced by photosynthesis

**glycerol:** complex molecule that is part of fats

**glycogen** (GLI kuh jun): starchlike carbohydrate in animals

**glycolysis:** series of energy-releasing reactions in a cell in the absence of oxygen; stage one of aerobic respiration though it does not require oxygen; process of anaerobic respiration

**goiter:** disease characterized by enlargement of the thyroid gland, often caused by lack of iodine in the diet

**Golgi** (GAWL jee) **body:** cell organelle which appears as stacks of flattened discs, thought to be involved with production of large carbohydrates and the storage and secretion of cellular substances

**gonads** (GOH nadz): sex organs; ovaries and testes

**grana** (GRAY nuh): platelike structures which contain chlorophyll in a chloroplast

**grassland:** biome of plains regions, characterized by grasses

**gray matter:** neuron cell bodies which make up the cerebral cortex and the interior of the spinal cord

**growth:** increase in the amount of living material in an organism; increase in the number of individuals in a population

**guanine** (GWAHN een): one of the bases in nucleic acids

**guard cells:** cells which surround and control the size of the stomata in leaves of complex plants

**gymnosperms** (JIM nuh spurmz): class of seed plants; plants in which seeds develop unprotected on the scales of cones; phylum Gymnospermae

**half-life:** time necessary for one half of a radioactive material to decay

**Haversian** (huh VUR zhun) **canals:** channels running throughout the bony layer that contain blood vessels and nerves which supply osteocytes

**hazardous wastes:** wastes dangerous to humans and other life forms

**head-foot mollusk:** mollusk which has tentacles originating in the head region such as squid and octopus

**heart:** muscular pump which circulates blood throughout an animal

**hemocoel** (HEE muh seel): body cavity, spaces through which blood passes in an open circulatory system

**hemoglobin** (HEE muh gloh bun): complex protein in red blood cells containing iron which combines with oxygen, important in oxygen transport

**hemophilia** (hee muh FIHL ee uh): sex-linked hereditary disease in which the blood fails to clot properly

**hepatic** (hih PAT ihk) **portal vein:** vein which carries blood from the intestine to the liver

**herbaceous** (hur BAY shus) **stem:** soft, green stem of plants which live for only one growing season

**herbivore** (HUR buh vor): consumer which eats producers (plants); plant eater

**heredity** (huh RED ut ee): transmission of characteristics from one generation to the next

**hermaphrodite** (hur MAF ruh dite): organism which has both ovaries and testes

**heterocyst** (HET uh roh sihst): special cell in a filament of blue-green algae that has thick walls, no DNA, and appears empty

**heterotroph** (HET uh ruh trohf): organism which cannot make its own food and so depends on other living or dead things for food

**heterozygous** (het uh roh ZI gus): having two different alleles for a given character at the corresponding sites on homologous chromosomes

**hibernation:** state in which metabolism is reduced and energy expenditure is minimized; occurs in some animals during the winter months

**high energy bond:** bond which when broken provides a large amount of chemical energy

**high energy phosphate:** phosphate group containing high energy bonds

**hindbrain:** one of the three general areas of the vertebrate brain

**hinge joint:** joint which moves in one direction and does not rotate

**histones:** very basic proteins that play an important role in chromosome structure

**holdfast:** special anchoring cell found in some algae

**homeostasis** (hoh mee oh STAY sus): maintaining of a constant internal environment

**hominid:** early human

***Homo erectus:*** prehuman that lived about 1.5 million years ago; may have led to the extinction of *Australopithecus*

***Homo habilis:*** prehuman that lived 2 to 3 million years ago; thought to be a toolmaker

***Homo sapiens*** (HOH moh • SAY pee unz): scientific name for modern humans

**homogeneous** (hoh muh JEE nee us): the same throughout

**homologous** (huh MAHL uh gus): those parts in various animals having the same shape, structure, and origin

**homologs** (HOH muh lawgs): the two chromosomes of a pair with the same kinds of genetic messages

**homozygous** (hoh muh ZI gus): having two identical alleles for a given character at the corresponding sites on homologous chromosomes

**hormone:** a chemical regulator that is produced in one part of the organism and affects other parts; complex molecules that direct chemical control within the body

**host:** organism from which another organism benefits

**humus:** rich layer of soil containing decayed remains of organisms

**hybridoma** (hi brih DOH muh): cell used to make cancer cells in the laboratory

**hydrocarbons:** compounds of hydrogen and carbon produced when fossil fuels are burned

**hydrogenase** (hi DRAHJ uh nays): an enzyme that removes hydrogen

**hydrolysis** (hi DRAHL uh sus): chemical reaction in which large molecules are broken into small molecules by the addition of water

**hyphae** (HI fee): filamentous strands filled with cytoplasm and many nuclei that compose the bodies of most true fungi

**hypocotyl** (HI puh kaut ul): embryonic seed structure, develops into part of the root and stem; embryonic part between the epicotyl and radicle

**hypothalamus** (hi poh THAL uh mus): region of the brain which controls many of the body's internal activities; brain region involved in many feedback mechanisms of internal control

**hypothesis:** idea or statement which explains the relationship among observed facts

**identical twins:** twins which have the same genotypes, resulting from the splitting of a zygote into two separate parts

**ileum** (IHL ee um): bulk of the small intestine in which most chemical digestion takes place; last portion of small intestine between jejunum and colon

**immune system:** cells and tissues which identify and defend the body against foreign chemicals and organisms

**immunity:** resistance to disease

**immunology:** study of how the body protects itself from invading organisms and chemicals

**imperfect flower:** flower which contains only the male or female organs

**implantation:** attachment to and embedding of the embryo in the uterine wall

**imprinting:** simple, rapid, irreversible form of learning by which an animal forms a social attachment to an object or organism shortly after hatching or birth

**improvement cutting:** removing old, crooked, or diseased trees while leaving the healthy trees

**impulse:** series of action potentials

**incomplete dominance:** condition in which the heterozygous genotype for certain alleles gives rise to a phenotype intermediate between the dominant and recessive traits

**incomplete metamorphosis:** three stage process of development in insects

**incurrent pore:** opening or perforation through which water enters a sponge

**indoleacetic** (IHN dohl uh seet ihk) **acid (IAA):** auxin necessary for the lengthening of plant cells

**inducer:** substance which causes enzyme induction

**industrial melanism** (MEL uh nihz um): phenomenon in which a color change in a population of peppered moths in England evolved during a period of industrialization

**infectious disease:** disease caused by a pathogen

**infusion:** nutrient-rich solution in which microorganisms can live

**ingestion:** taking in of bits of food not yet digested

**inheritance of acquired characteristics:** invalid hypothesis which states that characteristics which each individual acquires during its lifetime are passed on to the offspring of that individual

**inhibition** (ihn uh BIHSH un) **center:** area of the medulla oblongata from which the vagus nerves originate

**innate** (ihn AYT) **behavior:** behavior that is genetically passed from parent to offspring; behavior which does not change

**inner bark:** layer of a woody stem made up of cortex and phloem tissue

**inner cell mass:** one of the two regions of cells that form as the cells of a blastocyst divide

**insectivorous plant:** plant which feeds on insects

**insects:** largest class of arthropods; arthropods with three pairs of legs, three body sections, and usually wings

**insight:** ability to plan a response to a new situation

**inspiration:** process in which air is taken into lungs

**instinct:** innate behavior that involves complicated responses to a stimulus or stimuli

**insulin:** hormone which regulates the level of sugar in the blood; hormone secreted by beta cells of the islets of Langerhans

**insulin pump:** device which supplies the body with a constant flow of insulin

**integrated pest management:** system in which a combination of techniques is used to control pests

**integument** (ihn TEG yeh ment): outer covering of a seed; skin

**interferon** (ihnt ur FIHR ahn): protein produced by some cells after exposure to viruses which inhibits further virus growth

**internal fertilization:** process in animals in which sperms are deposited inside the female reproductive organs where fertilization occurs

**internal respiration:** exchange of gases within the body of an organism

**International System of Measurement:** special language of measurements and their symbols used by scientists and by other people in most countries throughout the world

**interphase** (IHNT ur fayz): period between mitoses during which chromosomes are replicated; period before meiotic division

**interpretation:** the logical conclusion drawn from observations made in the laboratory

**interspecific** (ihn tur spih SIHF ihk) **competition:** competition between populations of different species

**intestine:** alimentary canal organ where some or most food is chemically digested

**intracellular** (ihn truh SEL yuh lur) **digestion:** digestion which occurs within individual cells

**intraspecific** (ihn truh spih SIHF ihk) **competition:** competition between members of the same species

**intron:** DNA sequence that does not code for a protein

**invertebrates:** animals without backbones

**involuntary muscles:** muscles which an organism cannot consciously control

**ion:** charged atom or group of atoms

**ionic bond:** attraction between ions of opposite charge

**ionic compound:** combination of different ions

**islets** (I lutz) **of Langerhans** (LAHNG ur hahnz): endocrine cells within the pancreas which secrete insulin and glucagon

**isomers** (I suh murz): compounds which have the same chemical formula but different structural formulas

**isotopes** (I suh tophs): two or more atoms of the same element differing only in the number of neutrons

**Java people:** variety of *Homo erectus* that lived about 500 000 years ago

**jejunum** (jih JEW num): short section of the small intestine between the duodenum and the ileum

**joint:** where body segments of arthropods meet; where bones of vertebrates meet

**jungle:** dense forest community resulting from secondary succession of a rain forest

**juvenile hormone:** hormone involved in the final transition of an insect pupa to the adult form

**karyotype** (KER ee uh tipe): characteristics of all chromosomes in a cell including size and number

**kelp:** seaweed

**kidneys:** excretory organs in vertebrates

**kilogram:** an SI unit of measure for mass, equal to 1000 g

**kinetic energy:** energy of motion or energy at work

**kingdom:** broadest division in the classification of living organisms; the five kingdoms are animals, plants, protists, fungi, and monerans

**Klinefelter Syndrome:** genetic problem of males with an XXY chromosome pattern

**Koch's postulates:** the methods by which Koch determined that a bacterium causes a specific disease

**Krebs cycle:** stage three in aerobic respiration; stage in which 16 hydrogen atoms and 2 ATP molecules are released per glucose molecule entering glycolysis

**labor:** series of contractions of the uterine muscles prior to giving birth

**lactase:** enzyme that breaks down lactose

**lacteal** (LAK tee ul): lymph vessel in villi which absorbs fatty acids and glycerol

**ladder-type nervous system:** nervous system in planarians and other flatworms; system composed of two ganglia and two major nerve cords connected at regular intervals by nerves

**Lamarckism:** theory of evolution proposed by Jean Baptiste de Lamarck; ideas which explained evolution of adaptations through laws of use and disuse and inheritance of acquired characteristics

**language:** form of communication in which symbols are used to represent ideas

**large intestine:** organ in humans which absorbs water from the undigestible materials, also called the colon

**larva:** developing organism leading an independent existence

**lateral aspects:** side edges of a bilaterally symmetrical organism

**lateral bud:** bud along the sides of branches that gives rise to new branches

**latitudinal** (lat uh TEWD nul) **succession:** continuous succession of community types from the equator to the poles

**law of conservation of energy:** energy can neither be created nor destroyed, but can be transformed into other kinds of energy

**law of conservation of mass:** during a chemical reaction, mass can neither be created nor destroyed

**law of dominance** (DAHM uh nuhns): the dominant form of a trait dominates or prevents the expression of the recessive form

**law of independent assortment:** different chromosomes separate independently during gamete formation

**law of segregation** (seg rih GAY shuhn): during gamete formation the pair of alleles responsible for each trait separate so each gamete contains only one allele for each trait

**law of use and disuse:** assumption that an animal could strengthen or develop part of its body by using it and that if a certain body part were not used, it would disappear; one of the two laws of Lamarckism

**leaching:** dissolving of minerals out of rock and soil by water

**leaf:** major photosynthetic organ of complex plants

**learned behavior:** behavior that can be changed

**lenticel** (LENT uh sel): tiny pore on a stem; site of gas exchange between the stem and atmosphere

**left ventricular assist device** (**LVAD**): device which takes over for the heart until a donor heart becomes available for a transplant

**lethal** (LEE thuhl): causing death

**lethal gene:** an allele that causes death

**leukemia:** cancer of blood-forming tissue

**leukocyte** (LEW kuh site): white blood cells produced in bone marrow, the spleen, and lymph nodes; protects the body against infection

**levels of organization:** different groups of biological parts (cells, tissues, and so on) organized to perform particular functions

**liana** (lee AHN uh): vinelike plant common in rain forests; rooted in the ground but with leaves in the canopy

**lichen** (LI kun): mutualistic combination of a fungus and an alga; often lives on rock or in other barren places

**ligament** (LIHG uh munt): connective tissue which connects bones together

**light:** radiant energy

**light reaction:** series of photosynthetic reactions which depend on light; portion of photosynthesis in which light energy is converted to chemical energy

**linear density gradient:** gradient in which density increases from one end of the tube to the other, but not in distinct steps

**linkage:** genes occurring on the same chromosome

**limiting factor:** aspect of the environment which prevents an increase in population size at any given time

**lipids:** class of organic compounds which includes fats, waxes, and oils; composed of carbon, hydrogen, and oxygen

**littoral** (LIHT uh rul) **zone:** area of the ocean close to shore and subject to the action of tides

**liver:** digestive organ; produces bile, destroys old red blood cells, stores glycogen; important in many processes of metabolism

**lock and key hypothesis:** each enzyme is specific for a given substrate because its shape matches that of the substrate

**locomotion:** movement of the total organism

**long-day plant:** plants whose flowering is dependent on long periods of light exposure

**low energy phosphate:** a phosphate group containing low energy bonds

**luminescent:** glows in the dark

**lungs:** moist internal organs for gas exchange in most amphibians and all reptiles, birds, and mammals

**luteinizing** (LEW teen i zing) **hormone** (**LH**): hormone which causes the follicle to rupture and the ruptured follicle to change to the corpus luteum; causes production of testosterone in males

**lymph:** fluid which escapes from the capillaries into the intercellular spaces and exchanges many materials with the cells

**lymph nodes:** structures scattered throughout the body, remove harmful substances from lymph

**lymph vessel:** vessel which channels lymph throughout the body

**lymphatic** (lihm FAT ihk) **system:** network of lymph vessels and lymph nodes

**lymphocyte** (LIMH fuh site): white blood cell involved in the formation of antibodies which destroy foreign protein

**lysis** (LI sus): destruction of bacteria or other cells by breaking of the membrane

**lysogenic** (li suh JEN ihk) **cycle:** viral life cycle in which the DNA of a phage becomes part of the bacterial host's DNA and is replicated when the bacterium reproduces

**lysosome** (LI suh sohm): organelle containing chemicals which hydrolyze large molecules brought into the cell

**lytic cycle:** viral life cycle in which viral DNA takes over a bacterial cell, uses the bacterium's materials to reproduce, and destroys the bacterial cell

**macronucleus:** large structure in ciliates that controls the basic activities of a cell

**macrophage** (MAK ruh faj): kind of white blood cell involved in immunity

**magma:** molten material from deep within the earth

**magnification:** the amount an object is made bigger through the use of instruments such as microscopes

**malaria:** protozoan disease transmitted by mosquitoes which causes bursting of red blood cells

**malnutrition:** inadequate supply of one or more essential nutrients in a person's diet

**Malpighian** (mal PIHG ee un) **tubules:** cluster of stringlike structures attached to the intestine of a grasshopper that absorb nitrogenous wastes

**maltase:** enzyme that breaks down maltose

**mammals:** complex vertebrates which have hair or fur and mammary glands, and bear their young alive; class Mammalia

**mandible:** mouthpart adapted for biting and chewing

**mantle:** folded tissue in mollusks covering the internal organs

**marrow:** tissue in the hollows of some bones; produces blood cells or stores excess fat

**marsupials** (mar SEW pee ulz): group of pouched mammals in which partial development of embryos occurs internally

**masked message:** RNA sequence coated with protein and stored in the cytoplasm of a cell

**mass:** amount of material in an object

**matter:** anything which has mass and occupies space

**maturation region:** area of meristem where cells are large and develop into different types of specialized tissue

**medium:** substance in which an organism lives

**medulla** (mih DEW luh): inside part of a kidney; inside section of an adrenal gland

**medulla oblongata** (mih DEW luh • ahb long GAHT uh): portion of the hindbrain; controls involuntary responses of internal organs

**medusa:** jellyfish form of many coelenterates

**megaspore** (MEG uh spor): cell which divides in a female plant to form eight monoploid nuclei to form the female gametophyte generation

**meiosis** (mi OH sus): process of division whereby each sperm and egg receives the monoploid number of chromosomes

**melanin** (MEL uh nun): a dark pigment

**membrane potential:** condition in which the outside of the membrane is more positively charged than the inside; also called resting potential

**meninges** (muh NIHN jeez): membranes which protect and nourish the spinal cord and brain

**menopause:** period when the menstrual cycle of human females ends, usually occurs in the 40's

**menstrual** (MEN strul) **cycle:** monthly series of hormonal changes leading to egg maturation and uterine preparation for a possible pregnancy

**menstruation** (men STRAY shun): stage of the menstrual cycle usually lasting from three to five days during which blood, some uterine tissue, and the unfertilized egg are expelled from the vagina

**meristem** (MER uh stem): special regions of plant tissue where cell division occurs

**mesozoic:** era of the geologic timetable which lasted from 205 555 555 to 75 000 000 years ago

**mesoderm** (MEZ uh durm): layer of cells between the ectoderm and the endoderm

**mesoglea** (mez uh GLEE uh): jellylike layer between the two cell layers of coelenterates

**messenger RNA:** RNA which carries the genetic code of DNA; necessary for protein synthesis

**metabolism** (muh TAB uh lihz um): total of the chemical reactions which build up and tear down complex molecules within a cell

**metamorphosis** (met uh MOR fuh sus): series of changes in form during development of an immature form to an adult

**metaphase** (MET uh fayz): phase of mitosis in which chromosomes move to the "equator" of the cell and become attached to spindle fibers by their centromeres

**metre:** SI unit of linear measure

**methyl group:** a carbon atom bonded to three hydrogen atoms

**methylation:** adding of methyl groups to inactive genes to make them active

**microbe:** microscopic living thing

**microenvironment:** small area in an ecosystem which differs from the rest of the area

**microfilament:** structure that makes up the fibrils of skeletal muscle

**micron:** unit of length equal to 0.001 mm

**micronucleus:** small structure in celiates involved in reproduction

**microorganism:** living thing too small to be seen with the unaided eye; microbe

**micropyle** (MI kruh pile): opening in the ovule of a flowering plant through which sperm nuclei enter

**microscope:** a scientific instrument used to magnify small objects so that they can be easily seen

**microscopic** (mi kruh SKAHP ihk): too small to be seen with the naked eye

**microspores:** monoploid cells produced in the anthers of flowers

**microtubule:** long, thin structure that provides support and shape to a cell

**midbrain:** one of the three general areas of the vertebrate brain

**migration:** seasonal movement of animals

**millimetre:** linear measurement in SI that equals 1/1000 of a metre

**millipede:** member of class of arthropods characterized by two pairs of legs per segment; class Diplopoda

**mimicry** (MIHM ih kree): protective adaptation in which one organism (the mimic) resembles another organism (the model)

**mineral:** essential nutrient needed for maintenance of an organism

**mitochondria** (mite uh KAHN dree uh): organelles scattered throughout the cytoplasm; involved in energy release of respiration

**mitosis** (mi TOH sus): process of nuclear replication in a cell

**mixed nerves:** spinal nerves which contain both sensory and motor neurons

**model:** organism a mimic is similar to; image of an idea or object that helps simplify understanding the idea or object

**molecule:** a combination of two or more atoms joined by a covalent bond

**mollusks** (MAHL usks): soft-bodied, mostly marine animals, usually enclosed within a hard outer shell of calcium carbonate; phylum Mollusca

**molting:** process of shedding the exoskeleton in arthropods; process in some birds and reptiles in which the outer skin or feathers are shed and replaced by new growth

**moneran:** an organism in the Kingdom Monera

**monoclonal antibody:** antibody produced by one type of clone of cancer cells

**monocotyledonous plants (monocots):** plants whose seeds contain one cotyledon

**monoploid** (MAHN uh ployd) **number:** number of chromosome pairs in each cell; number of chromosomes in the gametes

**monosaccharide** (mahn uh SAK uh ride): single sugar; basic building block for complex carbohydrates

**monotreme:** group of primitive egglaying mammals; includes platypus and spiny anteater

**morphogenesis** (mor fuh JEN uh sus): series of embryonic changes in which migration of cells results in a change of form

**morphological** (mor fuh LAHJ ih kul) **adaptation:** adaptation which involves the structures of organisms

**mosaic:** mottled

**motivation** (moht uh VAY shun): drive necessary for the learning process of most animals

**motor neuron:** neuron which transmits outgoing impulses from the brain or spinal cord to the effectors

**mouthbreeder:** an animal which picks up and holds their fertilized eggs in its mouth until the eggs hatch

**mucin** (MYEWS un): substance in saliva which moistens food so it can be swallowed easily; mucus

**multicellular:** composed of many cells

**multiple alleles:** three or more alternate genes which can be at one site at different times giving different phenotypes, such as A, B, O genes for blood types

**multiple genes:** crosses in which many genes may affect a single trait

**multiple sclerosis:** disease which leads to the slow destruction of the nervous system

**murein** (MYOOR ee un): material that composes the cell wall of prokaryotes

**muscle:** specialized tissue which contracts

**muscle tone:** condition in which muscles are always slightly contracted

**mutagen** (MYEWT uh jun): agent which causes mutations by altering the structure of DNA molecules

**mutation** (MYEWT ay shun): change in the genetic code of an organism

**mutualism** (MYEW chuh lihz um): relationship in which two organisms live in a mutually beneficial and usually necessary association

**mycelium** (mi SEE lee um): mass of hyphae

**myelin** (MI uh lun) **sheath:** fatty outer layer which encloses the axon of many neurons

**myosin** (MI uh sun): protein which makes up part of the filaments in striated muscle

**NAD:** nicotinamide adenine dinucleotide, coenzyme which transports hydrogens and thus electrons in respiration

**NADP:** nicotinamide adenine dinucleotide phosphate, coenzyme which transports hydrogens and thus electrons during light reactions of photosynthesis

**nanometre:** SI unit of measurement used for very small things such as cell parts

**natural birth control:** method of birth control in which the chance of fertilization is reduced by abstaining from sexual intercourse near the time of ovulation

**natural selection:** process by which the better adapted organisms survive and reproduce

**navel:** point at which the umbilical cord was attached to the body of the baby during its development in the uterus

**Neanderthals** (nee AN dur thawl): humans that lived 35 000 to 100 000 years ago; classified as *Homo sapiens*

**nekton** (NEK tun): ocean animals which can move freely through the water under their own power

**nematocyst** (nih MAT uh sihst): stinging cell of coelenterates such as hydra; used in trapping food

**nematodes:** roundworms; phylum Nematoda

**neoteny** (nee AWT un ee): retaining immature traits in the adult form

**nephridia** (nih FRIHD ee uh): pairs of excretory units in almost every segment of an earthworm

**nephridiopore** (nih FRIHD ee up por): small opening of each bladder to the outside of an earthworm; releases wastes

**nephron** (NEF rahn): tiny excretory unit in the human kidney

**nephrostome** (NEF ruh stohm): funnel-shaped part of nephridia

**neritic** (nuh RIHT ihk) **zone:** area of ocean along the continental shelf beyond the littoral zone

**nerve:** bundle of neuron fibers

**nerve impulse:** series of action potentials sweeping down an axon

**nerve net:** diffuse nerve system within the mesoglea of coelenterates

**nervous system:** system which controls rapid responses to stimuli

**neural** (NOOR ul) **folds:** raised cells of the neural plate in the developing embryo

**neural plate:** rapidly dividing ectoderm cells which form a flat section along the dorsal side of an embryo

**neural tube:** hollow groove formed by the fusion of the neural folds; becomes the brain and spinal cord of the organism

**neurofibril** (noor oh FIBE rul): structure which transmits impulses in some protists

**neuron** (NOO rahn): specialized cell of the nervous system which conducts impulses; nerve cell

**neuropeptide:** small protein that functions in the nervous system

**neurotransmitter:** hormonelike chemical stored and released from tiny cavities at the ends of presynaptic fibers; secreted across synapses

**neutral solution:** solution which is neither acidic nor basic

**neutron:** neutral particle in the nucleus of an atom

**nicotine:** stimulant found in cigarette smoke

**night blindness:** disease caused by lack of vitamin A

**nitrification** (ni truh fuh KAY shun): process in which bacteria oxidize ammonium ions into nitrite ions and then to nitrate ions

**nitrogen base:** a compound that makes up part of a nucleic acid

**nitrogen cycle:** the movement of nitrogen through an ecosystem

**nitrogen fixation:** process in plants in which nitrogen gas is changed to a usable form

**nitrogen-fixing bacteria:** bacteria which convert atmospheric nitrogen to nitrate ions

**nitrogenous** (ni TRAHJ uh nus) **waste:** animal waste product, contains nitrogen

**node:** place on a stem where leaves develop

**nodes of Ranvier:** points where the myelin sheath does not cover the axon

**nodule** (NAHJ ewlz): swollen area on a root; contains nitrogen-fixing bacteria

**nonbiodegradable** (nahn bi oh dih GRAYD uh bul) **substance:** material which cannot be converted chemically to inactive compounds

**nondisjunction** (nahn dihs JUNK shun): failure of homolog to segregate during meiosis

**nonrenewable resource:** resource which once used cannot be replaced

**nonsymbiotic theory:** theory that explains the origin of eukaryotes through direct evolution of prokaryotes

**nonvascular plants:** plants that do not have vascular (conductive) tissue for transport of food, water, and minerals

**noradrenaline** (nor uh DREN ul un): neurochemical which excites heart muscle and inhibits alimentary canal muscles in humans

**notochord** (NOHT uh kord): stiff rod of cartilage along the dorsal side of chordates at some stage of their life cycle; becomes the vertebral column in most adult chordates

**nuclear fission:** process in which radioactive isotopes of uranium are split

**nuclear fusion:** reaction in which small atoms collide to form larger atoms, releasing energy

**nuclear membrane:** membrane which surrounds the nucleus

**nucleic** (noo KLAY ihk) **acids:** large, complex molecules, control heredity (DNA and RNA)

**nucleoli** (new KLEE uh li): small bodies within the nuclei of most eukaryotic cells; site of synthesis of RNA or ribosomes

**nucleoplasm** (NEW klee uh plaz um): protoplasm inside the nucleus

**nucleoprotein** (new klee oh PROH teen): combination of nucleic acid and protein; makes up chromosomes of eukaryotes

**nucleotide** (NEW klee uh tide): subunit of nucleic acids, composed of a sugar, a phosphate group, and a nitrogen base

**nucleus:** central, round body that is the control center of a cell

**nutrient** (NEW tree unt): in general, materials required by cells

**nutrient broth:** substance used for growing bacteria

**nutrition:** the study of foods and how they are used by the body

**nymph** (NIHMF): second stage in the process of incomplete metamorphosis

**oak-hickory forest:** climax community in the southeastern United States

**observation:** a noticed and recorded event

**ocean:** aquatic community covering over two thirds of the Earth's surface

**octet rule:** rule which states that atoms combine so that outer energy levels acquire eight electrons

**omnivore** (AHM nih vore): consumer which feeds on both producers and other consumers; consumer that eats plants and animals

**ootid:** cell produced in meiosis II that develops into a mature ovum

**open circulatory system:** system in which blood is not always in the blood vessels

**operator gene:** region of DNA with which a repressor combines inhibiting enzyme formation

**operculum** (oh PUR kyuh lum): hard covering of the gill chamber of fish

**oral groove:** opening in *Paramecium* through which food is ingested

**order:** subdivision of a class in the complete classification of an organism

**organ:** group of specialized tissues performing a specific function

**organelle** (or guh NEL): specialized cell part

**organic chemistry:** the study of chemistry of carbon compounds

**organic compounds:** molecules which contain the element carbon

**organism:** living thing

**organization:** the orderly functioning of a living system

**organizer:** tissue which induces other tissues of an embryo to differentiate

**organ of Corti:** special hair cells in the cochlea of the ear

**osculum** (AHS kyuh lum): large opening in the body of sponges; also called excurrent pore

**osmosis** (ahs MOH sus): diffusion of water across a semipermeable membrane

**osmotic** (ahs MAHT ihk) **balance:** equilibrium of water concentration inside and outside a cell

**ossification** (ahs uh fuh KAY shun): hardening of cartilage tissue into bone by the addition of minerals

**osteocyte** (AHS tee uh site): living bone cell

**ostia** (AHS tee uh): tiny openings through which blood passes into the heart of a grasshopper

**outer bark:** outermost part of a woody stem made up of cork

**oval window:** membrane in the middle ear

**ovary** (OHV ree): swollen lower region of the pistil in flowering plants; female gonad in animals; where eggs are produced

**oviduct** (OH vuh dukt): tube close to each ovary in the mammalian female; conveys egg from ovary to uterus; also called Fallopian tube

**ovipositor:** posterior abdominal segments of female grasshoppers used to tunnel into the soil

**ovisac:** structure in female frogs that stores eggs

**ovulation** (ahv yuh LAY shun): short stage in the menstrual cycle in which the follicle bursts and the mature egg is released

**ovule** (OHV yewl): female sporangium within the ovary of a flowering plant

**ovum:** egg

**oxidation reaction:** exergonic reaction in which oxygen is added to a substance, hydrogen is removed, or electrons are removed from a substance

**oxygen debt:** the amount of oxygen needed to remove the lactic acid from muscle cells and restore the supplies of stored energy

**oxyhemoglobin** (ahk sih HEE muh gloh bun): compound containing oxygen and hemoglobin; form in which oxygen is transported by red blood cells

**oxytocin** (ahk sih TOHS un): hormone secreted by the posterior pituitary; stimulates contraction of uterine muscles during labor

**pacemaker:** small bundle of tissue in the right atrium where the impulse for the heartbeat originates; also known as the sinoatrial node

**paleozoic:** era of the geologic timetable which lasted from 500 000 000 to 205 000 000 years ago

**palisade cells:** long cells arranged vertically under the epidermis of a leaf; site of photosynthesis

**palmate** (PAL mayt): venation pattern in which large veins originate and spread out from the point where the petiole is attached to the blade

**palmately compound:** leaf pattern in which leaflets are all attached to the petiole at a central point

**PAN:** compound of nitrogen oxides and hydrocarbons which pollutes the air, damaging lungs and irritating eyes

**pancreas** (PAN kree us): organ which secretes enzymes for intestinal digestion and the hormones insulin and glucagon

**pancreatic amylase:** enzyme which changes starch to maltose

**pancreatic duct:** duct which transports digestive enzymes from the pancreas to the duodenum

**parapods:** paired, bristled paddles that extend from the segments of some annelids, function in locomotion and respiration

**parasite:** organism that lives in or on a host and gets nourishment from the host

**parasitism** (PER uh suh tihz um): relationship in which one organism (parasite) is completely dependent on a host organism; the host is usually harmed

**parasympathetic** (per uh sihm puh THET ihk) **system:** division of the autonomic nervous system; counteracts the results of the sympathetic system's actions returning the body to normal after an emergency

**parental cross:** mating of two organisms to produce offspring; usually refers to first mating in a series

**parthenogenesis:** process in which male bees are hatched from unfertilized eggs

**passive immunity:** immunity to a disease brought about by the injection of an antiserum

**passive transport:** exchange of materials across the cell membrane in which the cell does not expend energy

**pasteurization:** heating and then rapidly cooling a substance to kill bacteria

**pathogen** (PATH uh jun): disease-causing organism

**pathogenic:** causing disease

**pecking order:** levels of authority in chickens and other animals; also called social hierarchy

**pedipalp:** a pair of appendages on spiders which hold and tear apart food

**Peking people:** variety of *Homo erectus* similar to Java people

**pellicle** (PEL ih kul): stiff covering on Ciliates

**pelvis:** central, hollow cavity of the kidney

**penicillin:** chemical produced by the mold, *Penicillium*; kills certain disease-causing bacteria

**penis:** male reproductive organ in animals which have internal fertilization

**pepsin:** enzyme which hydrolyzes proteins into polypeptides

**pepsinogen** (pep SIHN uh jun): protein present in gastric juice

**peptidase:** enzyme that converts small polypeptides to amino acids

**peptide:** two or more amino acids joined together

**peptide bond:** bond which holds amino acids together

**perfect flower:** flower which contains both male and female organs

**pericycle:** layer of root cells which gives rise to branch roots

**period:** subdivision of an era in the geologic timetable

**periostium** (per ee AHS tee um): outer layer of bones, encloses long bones such as arm and leg bones

**peripheral** (puh RIHF rul) **nervous system:** system which sends information from the receptors to the brain and spinal cord and transmits impulses from them to the effectors

**peristalsis** (per uh STAHL sus): series of alternating muscular contractions and relaxations, moves food along the digestive tract

**peritoneum** (per ut un EE um): thin sheet of tissue lining the coelum of segmented worms

**permafrost** (PUR muh frawst): layer of frozen ground in the tundra that never thaws

**pesticide:** chemical such as DDT that kills pests

**petiole** (PET ee ohl): slender stalk of a leaf, attaches leaf to the stem

**petrochemical** (peh troh KEM ih kul): extracts from fossil fuels

**pH scale:** scale of numbers representing the concentration of hydrogen ions and hydroxide ions in a solution

**phage:** a virus which attacks a bacterium

**phagocyte:** amoebalike white blood cell which engulfs and destroys invading microorganisms

**phagocytosis** (fag uh si TOH sus): engulfing of a solid particle by a cell

**pharynx** (FER ingks): tube through which food passes after it leaves the mouth in planarians and earthworms; in vertebrates, passageway for gases and food; throat

**phenylketonuria** (PKU): genetic disease in which a missing enzyme leads to severe mental retardation

**phenotype** (FEE nuh tipe): physical or visible characteristic which a genotype determines

**pheromone** (FER uh mohn): substance secreted by an organism into the environment which affects the physiology or behavior of other members of the same species

**phloem** (FLOH em) **cells:** cells which transfer food materials synthesized by the leaf to other parts of the plant

**photoperiodism:** response of flowering plants to light and dark conditions

**photosynthesis:** process by which light energy is absorbed and then converted to the chemical energy of glucose

**phototropism** (foh toh TROH pihz um): plant response to light

**phycocyanin:** a blue pigment found in blue-green algae

**phylum:** major classification division of a kingdom

**physical change:** any change in the physical properties of a substance

**physical property:** characteristic which describes a piece of matter

**physiological adaptations:** adaptations involved with the physical and chemical needs of organisms

**physiology** (fihz ee AHL uh jee): study of the functions of parts of living things

**phytochrome** (FITE uh krohm): pigment in leaves thought to be involved in flowering of flowering plants

**pinnate** (PIHN ayt): venation pattern in which veins branch from a central vein

**pinnately compound:** leaf pattern in which leaflets branch out along different parts of the petiole

**pinocytosis** (pi noh si TOH sis): a type of endocytosis in which liquids and small particles are taken into a cell

**pioneering stage:** first stage in ecological succession; usually involves hardy autotrophs

**pistil** (PIHS tul): long, vase-shaped female organ of a flower

**pith:** central part of stems

**pith ray:** cells which transport materials horizontally between pith, wood, and bark

**pituitary** (puh TEW uh ter ee) **gland:** tiny, endocrine gland at the base of the brain; secretes hormones which control other endocrine glands; also called the hypophysis

**pivot joint:** joint which moves in one direction as well as rotating

**placenta** (pluh SENT uh): mass of small blood vessels and associated tissues across which materials are exchanged between embryo and mother

**placentals** (pluh SENT ulz): group of mammals in which the entire development of the embryo occurs internally with material exchange occurring through the placenta

**plankton** (PLANG tun): marine organisms which float in the water

**plant:** autotrophic, complex, multicellular organism with chlorophyll in chloroplasts

**plasma cells:** clone of cells formed from a B-cell

**plasma membrane:** boundary which separates a cell from its environment; also called cell membrane

**plasmid:** circular segment of DNA in bacteria

**plasmodium** (plaz MOHD ee um): slimy mass of material in some species of slime molds, contains many nuclei but no cell walls

**plasmolysis** (plaz MAHL uh sus): loss of water from cells due to osmosis

**plastids** (PLAS tudz): organelles in plant cells, chloroplasts are the most common kind

**platelet** (PLAYT lut): blood cell fragments lacking nuclei; involved in blood clotting

**pneumonia:** respiratory disease that may be caused by bacteria, viruses, or fungi

**point of insertion:** site where a muscle attaches to a bone that moves

**point of origin:** site where a muscle attaches to a bone that does not move

**polar nuclei:** two monoploid nuclei within the ovule of a flowering plant that fuse with one of the sperm nuclei to form the endosperm nucleus

**polarity:** ionic charge

**polarized:** having an unequal distribution of ions (charge)

**pollen:** extension of the pollen grain through which sperm nuclei travel to the ovule

**pollen grain:** structure which contains the male sex cells of a flowering plant

**pollen sac:** male sporangium contained in flower anthers

**pollen tube:** structure formed by the tube nucleus that "digs" through the style to the ovary of a flower

**pollination:** process by which pollen reaches the female gametes

**pollutant:** any substance that makes water, soil, or air unclean

**pollution:** introduction of materials into the environment which decreases the purity, or cleanliness, of the environment

**polyp** (PAHL up): one of the body forms of coelenterates; sessile, cylindrical body

**polypeptide:** molecule formed by the union of many amino acids

**polysaccharide:** compound composed of many monosaccharides

**population:** group of organisms which naturally interbreed

**population density:** number of individuals per given area

**population genetics:** study of gene pools and their evolution

**population growth:** change in size of population with time

**population growth rate curve:** a graph of the rate of increase in the size of a population with time

**population size:** number of individuals in a population

**posterior** (pah STIHR ee ur): hind end of an organism

**posterior pituitary:** lobe of the pituitary gland; secretes oxytocin and vasopressin; does not directly influence other endocrine glands

**post-transcriptional event:** events that occur after transcription of DNA that can determine if the product of the gene is made

**postsynaptic** (pohst suh NAP tihk) **fiber:** fiber which receives an impulse after it crosses the synapse

**potential energy:** energy due to position; stored energy

**precambrian:** era of the geologic timetable which lasted from 5 000 000 000 to 500 000 000 years ago

**precipitate:** become solid

**predation** (prih DAY shun): feeding of one organism on another

**predator** (PRED ut ur): animal that preys on another organism

**prehensile** (pree HEN sul): able to grasp, like the human hand

**pressure-flow hypothesis:** explanation of food transport in plants in which pressure differences in sieve cells from leaves to roots account for the downward movement of food

**presynaptic** (pree suh NAP tihk) **fiber:** fiber which carries an impulse toward a synapse

**primary oocyte:** cell which divides in meiosis I to produce the secondary oocyte and first polar body

**primary spermatocyte:** cell which divides in meiosis I to produce two secondary spermatocytes

**primary succession:** ecological succession that begins with bare rock; the first succession in an ecosystem

**primate:** order of mammals which includes lemurs, monkeys, great apes, and humans

**proboscis** (pruh BAHS us): modified mouthparts of insects, used for obtaining food

**producer:** living thing which can make its own food

**product:** substance which results from a chemical reaction

**progesterone** (proh JES tuh rohn): hormone secreted by the corpus luteum; maintains the uterus in its prepared condition for pregnancy

**prokaryote** (proh KER ee oht): organism that does not have distinct nuclei; blue-green algae and bacteria

**prolactin:** hormone secreted by the anterior pituitary that stimulates milk production

**prophase** (PROH fayz): first stage in mitosis during which the nucleolus and the nuclear membrane disappear and chromosomes become clearly visible as separate bodies; stage in meiosis I when homologous chromosomes pair; stage in meiosis II

**prostaglandin:** special group of hormones made from fatty acids

**protease** (PROHT ee ays): enzyme which breaks down proteins

**protein:** large, complex molecule; contains carbon, hydrogen, oxygen, and nitrogen; building block of living material

**prothallium** (pro THAL ee um): small, heartshaped gametophyte of the fern

**prothrombin:** chemical needed for the clotting of blood

**protist:** simple, eukaryotic organism; includes simple algae, protozoa, and slime molds; Kingdom Protista

**proton:** positively charged particle in the nucleus of an atom

**protonema** (proht uh NEE muh): small, monoploid moss structure which grows into a mature gametophyte

**protoplasm** (PROHT uh plaz um): all the living substance of a cell

**protoplasmic streaming:** flow of protoplasm in a cell which distributes cellular material and, in some cases, aids locomotion

**protozoan:** unicellular, animallike protist

**provirus:** a virus which has become part of its host's DNA

**pseudopodia** (sewd uh POHD ee uh): structures of locomotion and foodgetting, false feet in amoeba

**psychology:** study of behavior

**puberty** (PYEW burt ee): onset of the development of secondary sexual characteristics

**pulmonary** (PUL muh ner ee) **artery:** artery in birds and mammals which takes deoxygenated blood from the right atrium to the lungs

**pulmonary veins:** veins in amphibians, reptiles, birds, and mammals which take oxygenated blood from the lungs to the left atrium

**Punnett** (PUN ut) **square:** chart used to determine the possible genotypes of the offspring of a cross

**punishment:** negative reinforcement

**pupa** (PYEW puh): stage of an insect life cycle in which the tissues of the organism are completely reorganized during complete metamorphosis

**pyloric sphincter:** structure that regulates the flow of chyme from the stomach into the small intestine

**pyramid of biomass:** relationship showing the decrease of biomass with each higher feeding level

**pyramid of energy:** relationship showing the loss of energy as it is transferred along a food chain

**pyramid of numbers:** relationship showing the decrease in the number of organisms with each higher feeding level

**pyrenoid** (pi REE noyd): structure on a chloroplast that stores excess food

**queen bee:** central figure in a beehive; mates only once and produces thousands of offspring

**radial symmetry** (SIH muh tree): body plan in which a cut lengthwise through the middle in any direction produces two identical halves

**radicle** (RAD ih kul): embryonic seed structure, becomes the primary root

**radiant energy:** energy given off as lightwaves

**radioactive elements:** isotopes with unstable nuclei which disintegrate, releasing nuclear energy

**radiocarbon dating:** method of dating fossils that uses the half-life of radioactive materials

**radula** (RAJ uh luh): structure with toothlike projections used by univalves and other mollusks to obtain food

**reactant:** substance which enters into a chemical reaction

**receptacle:** branch of a thallus of brown algae which contains sex organs

**receptor** (rih SEP tur): structure which detects stimuli; protein which "recognizes" and combines with certain other molecules (antigens, hormones)

**recessive** (rih SES ihv) **trait:** form of a trait which is dominated by another form

**recombinant DNA:** DNA that results from the combination of DNA from two organisms; recombined DNA

**recombination gametes:** gametes which have different allele combinations than the parental cells

**rectum** (REK tum): end of large intestine; storage area for solid wastes in mammals

**red cell:** blood cell that transports oxygen and some carbon dioxide

**red tide:** large population of dinoflagellates that present a danger to seafood and fish

**reflex:** innate behavior pattern resulting from the fixed pathways of the nervous system; simple response which involves no conscious control; also called reflex act

**reflex arc:** path of the impulse in a reflex

**refractory** (rih FRAK tree) **period:** interval of time in which the membrane potential of a neuron is being restored

**regeneration** (rih jen uh RAY shun): regrowing of missing parts; a method of vegetative propagation

**regulator gene:** gene which controls the production of a genetic repressor

**releasing factor:** hormone secreted by the hypothalamus if thyroxine levels fall below normal

**renal** (REEN ul) **arteries:** blood vessels which bring blood containing wastes to the kidneys

**renal veins:** blood vessels which return purified blood from the kidneys to the general circulation

**renewable resource:** resource which can be replaced

**replication:** duplication

**repressor:** special protein synthesized by mRNA that binds to operator gene and inhibits its function

**reproduction:** process in which new organisms are produced

**reproductive isolation:** any barrier to interbreeding

**reptiles:** vertebrates characterized by dry, scaly skin, internal fertilization and development within shelled eggs; class Reptilia

**resource:** anything humans take from the environment

**resolving power:** ability to distinguish two objects as two separate things

**respiration:** exchange of oxygen and carbon dioxide between cells and the environment

**respiratory system:** system made up of special regions for gas exchange and methods of transporting gases

**resting potential:** another name for membrane potential

**reverse transcription:** process in RNA tumor viruses in which DNA is made from RNA

**reward:** positive reinforcement for a behavior

**Rh factors:** antigens in the blood; first discovered in the blood of Rhesus monkeys

**Rh negative blood:** blood which does not have the Rh factors

**Rh positive blood:** blood which has the Rh factors

**rhizoid** (RI zoyd): rootlike structure which anchors certain fungi to the food source and secretes enzymes into it; rootlike structure in bryophytes

**rhizome** (RI zohm): underground fern stem from which roots and leaves develop

**ribonucleic** (ri boh noo KLAY ihk) **acid** (**RNA**): large, complex molecule which works with DNA in carrying out the instructions of the genetic code

**ribose:** sugar contained in RNA

**ribosomal RNA:** type of RNA that makes up ribosomes

**ribosome** (RI buh sohm): organelle in cytoplasm which is the site of protein synthesis

**rickets:** disease caused by lack of vitamin D which results in the improper development of bone

**rickettsia** (rihk ET see uh): group of disease-causing organisms which are parasites

**rift:** crack in the Earth's crust

**RNA processing:** post transcriptional event which occurs in the nucleus of a cell

**RNA tumor virus:** virus known to cause tumors in animals

**root cap:** protective cells covering the tip of a growing root

**root hair:** outgrowth of a root epidermis cell

**root pressure:** pushing force caused by water in the xylem

**round dance:** bee behavior which means there is food within 100 m

**rust:** club fungi which causes disease in plants

**saliva** (suh LI vuh): liquid secretion of the salivary glands; moistens food and contains an enzyme which breaks starch into maltose

**salivary** (SAL uh ver ee) **glands:** three pairs of glands which secrete saliva

**saprophyte** (SAP ruh fite): organism which obtains its food from dead organisms or from waste products of living things

**scanning EM:** electron microscope which passes a beam of electrons through a live sample, forming an image which can be viewed on a screen

**scavenger** (SKAV un jur): animal which feeds on dead animals

**science:** a body of organized knowledge about nature; method of solving problems

**scrotum** (SKROHT um): external sac which encloses the testes of a mammal

**second:** basic unit of time in SI

**second filial generation:** generation of offspring produced from interbreeding offspring of the first filial generation

**second messenger hypothesis:** idea that hormones cause cells to produce a second compound which acts as a messenger and causes chemical changes in the cells

**second-order consumer:** consumer which eats a first-order consumer

**second polar body:** cell produced from the secondary oocyte during meiosis II that dies

**secondary oocyte:** cell which undergoes meiosis II to produce the ootid, and a second polar body

**secondary spermatocytes:** two cells produced by meiosis I which undergo meiosis II to produce the spermatids

**secondary succession:** series of ecological changes which occur when species of a climax community are removed

**secretion:** process by which an organism releases some material; the material released

**seed:** reproductive structure which contains an embryo plant and endosperm

**seed coat:** hardened outer covering of a seed

**seed dispersal:** the scattering of seeds

**segmentation:** division of a body plan into more or less similar parts

**segmented:** divided into units

**segregate:** separate

**selective breeding:** mating of animals or plants to produce offspring with desired features

**selective cutting:** cutting of mature trees while leaving the young trees to mature

**self-pollination:** pollination which occurs in a single flower or between flowers on the same plant

**semen** (SEE mun): combination of sperms and fluid

**semilunar** (sem ih LEW nur) **valve:** valve at the base of the pulmonary artery or aorta; prevents blood from flowing back into the ventricle after it contracts

**semipermeable** (sem ih PER mee uh bul) **membrane:** membrane which allows only certain materials to pass through it

**sensory neuron:** cell which transmits incoming impulses from receptors to a coordinating center such as the brain or spinal cord

**sensory-somatic system:** division of the peripheral nervous system; controls the exchange of information between receptors, the central nervous system, and the skeletal muscles

**septum** (SEP tum): in some vertebrates, wall dividing ventricle which keeps oxygenated and deoxygenated blood separated

**sessile** (SES ul): permanently attached

**setae** (SEE tee): bristles on each segment of segmented worms; aid in locomotion

**sex chromosomes:** chromosomes (X and Y) which determine sex

**sex-linked characteristic:** trait whose genes are carried on the X chromosomes

**sexual reproduction:** union of two sets of DNA; fusion process

**sexually transmitted disease:** a venereal disease such as syphilis and gonorrhea

**shelled egg:** embryo surrounded by a tough shell; protects embryo as it develops outside the mother; permits development away from water

**short-day plant:** plant whose flowering depends on short periods of light exposure

**sickle-cell anemia:** hereditary disease in which hemoglobin is abnormal and red blood cells are shaped like sickles

**sieve tube:** another name for a phloem cell because the end walls are perforated, resembling a sieve

**simple formula:** chemical formula showing the kinds and numbers of atoms per molecule

**sinoatrial** (si noh AY tree ul) **node** (**S-A node**): small bundle of tissue in the right atrium in which the impulse for the heartbeat originates; also called the pacemaker

**sinus** (SI nus): space in the body cavity through which blood passes in animals with an open circulatory system

**sinus venosus** (SI nus • vih NOH sus): saclike structure in fishes and frogs which collects blood as it returns to the heart

**skeletal muscles:** another name for striated muscles

**skeletal system:** specialized support system in most complex organisms

**sliding filament hypothesis:** theory which explains muscle contraction

**slime capsule:** outer protective covering which encloses some bacteria cells

**slime mold:** fungi-related protist; phylum Myxomycophyta

**small intestine:** digestive organ in humans in which most chemical digestion occurs

**smooth ER:** endoplasmic reticulum without ribosomes

**smooth muscle:** muscle which moves many of the internal parts of the body; also called nonstriated or involuntary muscle

**smut:** club fungi which causes disease in plants

**social hierarchy** (HI rar kee): levels of authority in animals

**society:** group of animals of the same species living together in an organized way

**sodium-potassium pump:** process occurring in a neuron where sodium ions are actively transported out of and potassium ions into a cell

**soil depletion:** reduction of soil fertility as a result of nutrients being removed by crops

**sol** (SAHL): liquified state which the cytoplasm may take

**solute** (SAHL yewt): portion of a solution in lesser quantity

**solution:** homogeneous material with variable composition

**solvent** (SAHL vunt): portion of a solution in greater quantity

**sori** (SOR i): circular structures on the underside of leaves in some species of ferns; contain sporangia

**speciation:** evolution of a new species

**species:** classification division after genus; group of organisms which normally interbreed in nature to produce fertile offspring; second name in scientific name

**sperm:** male reproductive cell

**sperm duct:** area in the male reproductive system where fluids are added to the sperm

**sperm nuclei:** two monoploid nuclei produced by mitosis from the generative nucleus in the pollen tube

**sperm receptacle:** special sac attached to the vagina of a grasshopper used for sperm storage

**spermatids:** four monoploid cells produced during meiosis II which mature into sperm cells

**spicule** (SPIHK yewl): minerallike structure which supports a sponge

**spinal cord:** major nerve cord running along the dorsal side of vertebrates

**spinal nerves:** thirty-one pairs of nerves that connect body parts with the spinal cord in humans

**spindle:** oval-shaped structure composed of fibers between opposite poles of the cell; structure to which chromosomes become attached in mitosis and meiosis

**spinneret:** structures in a spider's body which release threads of silk for making webs

**spiracle** (SPIHR ih kul): small opening through which air enters a terrestrial arthropod; external opening of a trachea

**spirilla** (spi RIHL uh): spiral-shaped bacteria

**spleen:** saclike abdominal organ which mainly stores blood, destroys dead blood cells, and produces lymphocytes

**split gene:** gene which contains exons and introns

**sponges:** sessile, mostly marine animals with two cell layers; phylum Porifera

**spongy layer:** layer of cells beneath the palisade cells in leaves; contains chlorophyll

**spontaneous** (spahn TAY nee us) **generation:** mistaken belief that organisms can be produced from nonliving sources

**sporangiophore** (spuh RAN jee uh for) **hypha:** upright structure upon which sporangia are located; present in common bread mold

**sporangium:** case in which spores are produced and stored

**spore:** specialized reproductive cell which gives rise to a new organism

**sporophyte** (SPOR uh fite) **generation:** generation of a plant in which the cells are diploid and spores are produced

**sporozoans** (spor uh ZOH unz): phylum of protozoa that have no way of moving and reproduce by means of spores

**spring wood:** wood produced in the spring, consisting mainly of large xylem vessels

**S-shaped curve:** population growth curve

**stamen** (STAY mun): male reproductive organ of a flower

**starch:** large, complex molecule made up of hundreds of monosaccharides

**stele** (STEEL): central cylinder of the cortex of a root, xylem and phloem

**stem:** main stalk of vascular plants; supports the plant and transports materials

**step density gradient:** tube containing liquids in zones or steps of different density

**sterile:** free of life

**steroids** (STIHR oydz): group of organic compounds that includes cholesterol, sex hormones, hormones from the adrenal cortex, and vitamin D

**stigma:** structure on *Euglena* sensitive to light; sticky part of a female flower

**stimulant:** one of a major group of drugs which works by increasing the reactions of the central nervous system

**stimulus:** anything that causes activity or change in an organism

**stipe:** stalklike section of a mushroom

**stolon** (STOH lun): hypha which grows along the surface of the food supply

**stomata** (STOH mut uh): tiny pore in a leaf

**stomach:** large, hollow organ where protein digestion begins

**strata:** layers

**striated** (STRI ayt ud) **muscle:** muscle attached to bones; sometimes called skeletal muscle or voluntary muscle

**stroma:** liquid within a chloroplast which produces glucose

**structural formula:** formula which shows the arrangement of the atoms of a molecule

**structural gene:** gene which directs synthesis of a protein or polypeptide

**style:** stalklike portion of a pistil

**suberin** (SEW buh run): oily material which coats cork cells and protects against water loss

**subspecies:** division of species; capable of interbreeding with other subspecies of the same species; also called race

**substrate** (SUB strayt): molecule or molecules upon which a certain enzyme operates; surface upon which an organism lives or moves

**successive osmosis:** process in which water passes by osmosis from cell to cell and then into the xylem of roots

**sucrase:** enzyme that breaks down sucrose

**summer wood:** wood produced in the summer; made up of vessels that are smaller in diameter than those in spring wood

**survival of the fittest:** major point of Darwin's theory of evolution; the best-adapted organisms survive to reproduce

**swimmeret:** appendage on some crustaceans used for swimming

**swarm cells:** flagellated cells of slime molds which can fuse to form a zygote

**symbiosis:** a relationship in which two organisms live in close association and in general, both benefit from the relationship

**symbiotic theory:** theory that explains the origin of eukaryotes through symbiosis of prokaryotes

**sympathetic** (sihm puh THET ihk) **system:** division of the autonomic nervous system; initiates responses which prepare the body for emergencies

**synapse** (SIHN aps): gap between two neurons or between a neuron and effector

**synapsis** (suh NAP sus): process in which homologous chromosomes pair during prophase of meiosis I

**synfuels** (SIHN fyewlz): fuels made by artificial processes

**synthesize** (SIHN thuh size): build up

**synthetic vaccine:** vaccine made from pure antigens

**system:** group of organs working together to perform a specific function

**systole** (SIHS tuh lee): contraction of the heart chambers

**taiga** (TI guh): biome characterized by coniferous forests

**tail:** adenine molecules on the end of mRNA

**taproot system:** root system in which plants have one large, primary root

**target organ:** organ affected by a particular hormone

**taxonomy:** science of classifying things

**Tay-Sachs disease:** genetic disease in which the nervous system fails to develop properly

**T-cell:** lymphocyte which passes through the thymus gland

**technology:** applying scientific knowledge to real problems

**telophase** (TEL uh fayz): last phase of mitosis in which the events are opposite those of prophase; stage in meiosis I and meiosis II

**temperate deciduous forest:** biome characterized by an even distribution of rain totaling about one hundred centimeters per year; region in which leaves are periodically all shed from the trees

**tendon** (TEN dun): tough, elastic connective tissue which attaches muscle to bone

**tentacles** (TENT ih kulz): structures that surround the mouth of some animals, used in food getting

**terminal bud:** bud at the tip of a branch responsible for lengthening stems

**terracing:** conservation practice in which banks of land are created on slopes to prevent erosion from water runoff

**territoriality** (ter uh tor ee AL ut ee): adaptation in many animals to occupy and defend specific territories

**testis** (TES tus): male gonad

**testosterone** (teh STAHS tuh rohn): androgen which stimulates the formation of secondary sexual characteristics in males

**tetanus:** bacterial disease resulting in continuous muscle contraction

**tetrad** (TEH trad): pair of double-stranded chromosomes

**thallus:** the entire body of an alga

**theory:** fundamental hypothesis which has survived the test of time

**third-order consumer:** consumer which eats a second-order consumer

**thoracic duct:** major tube in the chest region for collecting lymph

**thorax:** chest region

**threshold:** level of intensity necessary to cause a nerve impulse

**thromboplastin:** chemical needed for the clotting of blood

**thymine** (THI meen): one of the bases in nucleic acids

**thymus gland:** gland beneath the breastbone; thought to control the production of certain antibodies in juveniles

**thyroid** (THI royd) **gland:** small endocrine gland on the trachea; secretes thyroxine

**thyroid-stimulating hormone** (**TSH**): hormone secreted by the anterior pituitary that stimulates thyroxine production

**thyroxine** (thi RAHK sun): hormone which controls the metabolic rate of the body cells; produced by the thyroid gland

**tissue:** similar groups of cells organized to perform certain functions

**tissue fluid:** fluid which passes out of the blood vessels and exchanges materials with tissue cells

**T-maze:** maze shaped like a T so an animal has a choice of one of two turns

**topsoil:** dark, upper layer of soil; most fertile layer

**toxin** (TAHK sun): poisonous chemical

**trachea** (TRAY kee uh): windpipe, tube leading from mouth to bronchi; tube in insects and spiders which opens to the outside, functions in gas exchange

**tracheal** (TRAY kee ul) **system:** system made up of spiracles, tracheae, and tracheoles; respiratory system in terrestrial arthropods

**tracheid** (TRAY kee ud): type of xylem cell

**tracheole** (TRAY kee ohl): tiny air sac which contains water; part of the tracheal system in terrestrial arthropods; site of gas exchange with cells

**tracheophytes:** plants characterized by vascular tissue; phylum Tracheophyta

**tranquilizers:** drugs which depress the central nervous system

**transaminase** (tranz AM uh nays): an enzyme that transfers an amino group

**transcription** (trans KRIHP shun): transferring the genetic code from DNA to RNA in protein synthesis

**transduction** (trans DUK shun): injection of portion of one bacterial chromosome into another bacterium by a bacteriophage

**transfer RNA:** RNA which brings amino acids to messenger RNA in protein synthesis

**transformation:** reproductive process which occurs when one bacterium breaks open and part of its DNA enters another bacterium

**transformer:** bacterium which converts nitrogen from organic to inorganic form

**transforming principle:** chemical involved in bacterial transformation; DNA

**translation:** operation and interaction of messenger RNA, transfer RNA, and amino acids to form a protein

**translocation** (trans loh KAY shun): transport of food in a vascular plant; occurs within phloem cells

**transmission EM:** electron microscope which passes a beam of electrons through a very thinly sliced sample

**transpiration** (trans puh RAY shun): process in which water constantly escapes from the leaves of plants through the stomata

**transpiration-cohesion theory:** theory that states that water is pulled up a stem because water loss through the leaf pulls on the water column in the xylem

**transpiration pull:** tension created by cohesion of water molecules to one another

**transport system:** system for exchange of materials between cells and the environment

**transverse colon:** section of the large intestine

**trial and error:** simple learning in which an organism repeatedly tries a task and learns by its mistakes

**trichinosis:** painful disease caused by the eating of pork containing *Trichinella* worms

**trichocyst:** structure in *Paramecium* used for protection

**tricuspid** (tri KUS pud) **valve:** valve between the right atrium and right ventricle; prevents blood from returning to the right atrium when the right ventricle contracts

**trimming:** removal of cap and tail of mRNA in the nucleus

**triploid** (TRIHP loyd): 3n structure

**tropical rain forest:** biome of equatorial regions, characterized by heavy rainfall, constant warm temperature, dense growth of many different species of trees

**trophoblast:** outer layer of cells which develops as the cells of the blastocyst divide

**tropism** (TROH pihz um): plant growth response caused by unequal stimulation on opposite sides of the plant

**trypsins:** protein-digesting enzymes secreted by pancreas

**tube feet:** hollow structures on the underside of a starfish; used in locomotion and food-getting

**tube nucleus:** one of the two monoploid nuclei formed in the anther of a flower

**tuber:** modified, swollen underground stem

**tubule:** tube which leads to the bladder in each nephridium of an earthworm; long, coiled tube leading from each Bowman's capsule in a kidney

**Turner Syndrome:** genetic problem resulting from nondisjunction of the sex chromosomes leaving the person with one X and no Y chromosome

**tundra** (TUN druh): biome characterized by low average temperature, permafrost, low average rainfall, lack of large plants

**turgidity** (tur JIHD ut ee): stiffness caused by the pressure of water in cells

**tympanic membrane:** eardrum

**ultrasonography** (ul truh suh NAUG ruh fee): technique used to determine the position and anatomy of a fetus

**umbilical** (um BIHL ih kul) **cord:** structure which contains blood vessels; transports blood between the embryo and the placenta

**uncoating:** the exit of RNA from the protein coat of a virus

**unicellular:** made up of only one cell

**univalve** (YEW nih valv): one-shelled mollusk

**universal donor:** person having type O blood

**universal recipient:** person having type AB blood

**uracil** (YOOR uh sihl): a base in RNA but not in DNA

**urea** (yoo REE uh): nitrogenous waste in amphibians and mammals; component of urine

**ureter** (YOOR ut ur): tube which transports urine from the kidney to the urinary bladder

**urethra:** canal from which urine is expelled from the body and in males transports sperms

**uric acid:** nitrogenous waste produced by insects and some other animals

**urinary bladder:** hollow organ which stores urine

**urine:** combination of urea, excess salts, and water

**uterus** (YEWT uh rus): thick-walled, muscular organ in female mammals; organ in which the embryo develops; also called the womb

**vaccine:** solution of weakened or killed microorganisms administered to prevent disease by producing immunity

**vacuole** (VAK yuh wohl): cellular organelle used for storage

**vagina** (vuh JI nuh): the organ in the female that receives sperm from the male

**vagus** (VAY gus) **nerves:** pair of nerves which originate in the medulla oblongata that decrease the heartbeat rate

**valve:** another name for *shell* in mollusks

**variable factor:** factor being tested in an experiment

**vascular bundle:** group of xylem and phloem tissue

**vascular cambium:** meristem which produces cells that later develop into xylem and phloem tissue

**vascular plants:** plants which have specialized tissue for the transport of food, water, and minerals

**vascular tissue:** tissue which transports food, water, and minerals throughout plants

**vasopressin** (vay zoh PRES un): hormone secreted by the posterior pituitary gland that controls water balance in the body

**vegetal** (VEJ ut ul) **pole:** ventral part of a frog egg; contains the yolk

**vegetative propagation** (VEJ uh tayt ihv • praph uh GAY shun): reproduction from a nonsexual, or vegetative, part of an organism

**vein:** conducting tissue of leaves (xylem and phloem); blood vessel which carries blood toward the heart from the body

**venation** (ve NAY shun): vein pattern in a leaf

**ventral** (VEN trul): belly side of an organism; toward the belly

**ventral aorta:** aorta that carries blood from the heart to the gills of a fish

**ventral blood vessel:** major blood vessel on the front side of an annelid worm

**ventricle** (VEN trih kul): chamber which pumps blood away from the heart; cavity or space within the brain

**vertebrae** (VUR tuh bray): bony structures which connect to form the spinal column in vertebrates

**vertebrates** (VURT uh brayts): animals with backbones

**vertical stratification:** layers of a forest from top to bottom

**vesicle:** sac which stores neurotransmitters

**vessel:** type of xylem cell

**vestige** (VES tihj): structure which is no longer functional

**villi** (VIHL i): structures on the intestinal lining which extend into the hollow of the intestine; increase the surface area for absorption of digested food

**viroid:** small segment of RNA known to cause disease in a variety of plants

**virus:** microscopic "organism" which depends on a specific host cell for its reproduction

**visible spectrum:** band of colors created when white light is separated into different wavelengths

**vitamin:** an organic substance necessary in small amounts for the proper metabolic functioning of an organism

**volume:** cubic capacity of an object

**voluntary muscles:** muscles that can be controlled

**waggle dance:** bee behavior which indicates distance (over 100 m) and direction to food source

**warning coloration:** display of various bright colors which announce rather than conceal the presence of an animal

**water-vascular system:** system which controls movement and food-getting in a starfish

**wavelength:** distance between consecutive crests of two waves

**weight:** measure of gravitational attraction between two objects

**weathering:** mechanical process of freezing, thawing, and erosion

**white matter:** axons with myelin sheaths in the interior of the human brain and exterior of the spinal cord

**womb:** uterus

**woody stem:** stem which contains woody tissue derived from xylem

**worker bee:** sterile female bee which performs most of the tasks necessary for maintaining a beehive

**X chromosome:** one of the chromosomes which determines sex; a sex chromosome

**X-ray crystallography** (krihs tuh LAHG ruh fee): scientific technique which uses X-rays to determine the structure of substances

**xylem** (ZI lum): vascular tissue in plants; carries water and minerals to the leaves

**Y chromosome:** one of the chromosomes which determines sex; a sex chromosome

**yolk sac:** structure in the shelled egg which contains yolk, the food source for the developing embryo

**zero population growth:** condition in which the birth rate equals the death rate

***Zinjanthropus*** (zihn JAN thruh pus): prehuman that lived about 1.75 million years ago, now thought to be a member of the genus *Australopithecus*

**Z-line:** crossband to which actin is attached

**zoospore:** asexual reproductive cell produced from sporangium cells

**zygospore:** diploid zygote with tough outer shell

**zygote** (ZI goht): fertilized egg resulting from the union of a sperm and an egg

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